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Department of Biology

**Floristic Composition and Structural Analysis of Woody Plant Species in Endiras Natural
Forest, Fogera District, Ethiopia**

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Debre Tabor, Ethiopia



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Approval sheet

This is to approve that this research was prepared by Worku Misganaw, entitled with Floristic Composition and Structural Analysis of Woody Plant Species in Endiras Natural Forest, Fogera District, Ethiopia and submitted in partial fulfillment of the requirements for the Degree of Master of Science (Botany) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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LIST OF ACRONYMS/ABBREVIATION

CCA	Canonical Correspondence Analysis
CEC	Cation Exchange Capacity
CSA	Central Statistical Agency
DBH	Diameter at Breast Height
EBI	Ethiopian Biodiversity Institute
ETH	Ethiopian National Herbarium
FAO	Food and Agriculture Organization of United states
GPS	Global Positioning System
GTZ	German Technical Cooperation
ha	hectare
IVI	Importance Value Index
km	kilometer
m	meter
m.a.s.l	meter above sea level
N	North
NBSAP	National Biodiversity Strategy and Action Plan
NE	North East
NW	North West
OM/OC	Organic Matter/ Organic carbon
PH	Power of Hydrogen
RD	Relative Density
RDO	Relative Dominance
RF	Relative Frequency
S	South
SE	South East
SW	South West

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ABSTRACT

*This study was conducted on Endiras Forest, Fogera District, South Gonder Zone of Amhara Region, 625 km North of Addis Ababa to identify the floristic composition and structure of woody species. Systematic sampling method was used to collect vegetation data from 50 (20 m x 20 m) plots. In addition, 5 m x 5 m for seedling and sapling subplots, 15 cm x 15 cm for soil samples was laid within the main plot four at the corners and one in the middle. DBH at 1.3 m of all trees and shrubs having diameter at breast height ≥ 2.5 cm was measured. Heights of all seedlings (individuals < 60 cm height), saplings (DBH < 2.5 cm and ≥ 60 cm height) and mature trees/shrubs (DBH ≥ 2.5 cm and ≥ 60 cm heights) was recorded. A total of 69 plant species in 57 genera and 36 families were recorded. Out of all species three were found to be endemic to Ethiopia. The family Fabaceae with 15 species had the highest number of species followed by Euphorbiaceae and Moraceae. Woody species densities for mature individuals were 3,252.5 stems ha^{-1} , seedlings 5398.4 stems ha^{-1} and sapling 4782.4 stems ha^{-1} . Analysis of IVI indicated that *Carissa spinarum* had the highest value (21.19). The study revealed the prevalence of small-sized individuals (64.41%) in Endiras Forest was found in lower DBH classes. Four population distribution patterns were recognized, i.e., inverted- J, irregular, bell-shaped and J-shaped patterns. Population structure and regeneration status of selected woody species were assessed and results revealed that some species had regeneration problems and need management measures. Eight environmental gradients (altitude, aspect, browsing, pH, and sand, OC, P and Ca) have a great share to determine the distribution of vegetation with various extents. Therefore, to have full information about the regeneration status and the use of the forest, detailed seed bank study and ethnobotanical study of the forest was recommended.*

Key Phrases/Words: Endiras Forest, Floristic composition, Plant community, Conservation, Regeneration and Vegetation.

1. INTRODUCTION

1.1. Background of the Study

Ethiopia is one of the top 25 biodiversity-rich countries in the world (WCMC, 1994), and hosts two of the world's 34 biodiversity hotspots, namely the Eastern Afromontane and the Horn of Africa hotspots. It is also among the countries in the Horn of Africa regarded as major center of diversity and endemism for several plant species. The Ethiopian flora is estimated to about 6027 species of higher plants of which 10% are considered to be endemic (Ensermu Kelbessa and Sebsebe Demissew, 2014). Woody plants constitute about 1000 species out of which 300 are trees.

Ethiopia has great topographical diversity with flat-topped plateaus, high mountains, river valleys, deep gorges, rolling plains, and with great variation of altitude from 126 meters below sea level to 4620 m.a.s.l. (NBSAP, 2005). These helped the emergence of wide ranges of habitats that are suitable for the evolution and survival of various plant and animal species. As a result, the country is regarded as one of the most important countries in Africa with respect to endemism of plant and animal species in tropical Africa (EWNHS, 1996). However, the high increase in the population, livestock pressure and increased demand for arable land are causing a significant reduction of forest resources (Mulatie Mekonnen *et al.*, 2016). The need for fuel-wood, arable land and grazing areas have been indicated as the main causes of forest degradation frequently leading to loss of forest cover and biodiversity, desertification, erosion and reduced water resources (Mulatie Mekonnen *et al.*, 2016).

Botanical assessments such as floristic composition, species diversity and structural analysis studies are essential for providing information on species richness of the forests, useful for forest management purpose and help in understanding forest ecology and ecosystem functions (Pappoe *et al.*, 2010). Information on floristic composition and structure of forest is also helpful in identifying ecologically and economically important plants and their diversities, protecting threatened and economical important plant species (Addo-Fordjour *et al.*, 2009). Therefore, an urgent need to study the species diversity of the area and determine their conservation status, before their respective populations and associated natural habitats degraded beyond a limit of no return. The duly resulting information would be essential for developing appropriate

conservation methods. This is crucial, in order, to safeguard threatened species, their provenances and ecosystems from further depletion. Even if this study only covers small area when one considers the total coverage of Ethiopian forests, it is vital to help the sustainable management of the forest in the study area.

1.2. Statement of the Problem

In many parts of the world, particularly in developing countries natural forest vegetation cover is diminishing at an alarming rate. This results in unprecedented loss of biological diversity. In addition, basic information on the extent distribution, species composition and the rate of deforestation in Ethiopia is very limited (Fekadu Gurmessa, 2015).

The forest biodiversity is an important renewable natural resource serving tremendous values of scientific, agricultural, medical, pharmaceutical, educational, cultural and ecological importance. They are repositories of plant genetic resources which serve as home of other biodiversity. Moreover, in the recent global environmental crisis, they act as important carbon sink. In Ethiopia about 40% of the land area was covered with forests at the turn of the 19th century which is declined to 16% in 1950s, 3.6% in the early 1980s and further down to 2.7% in 1989 (EFAP, 1994). A recent analysis on the rate of deforestation shows that the country's forest resource is rapidly declining at the rate of 141,000 ha per year (FAO, 2010).

The direct and indirect economic dependence of the fast-growing rural population on agriculture and absence of alternative economic activities resulted in conversion of forests into agricultural and other land use systems (Demel Teketay, 2001). Consequently, environmental crises such as soil erosion, fragmentation of habitats, loss of biodiversity, loss of the role of carbon sequestration and the regulation of global warming coupled with subsequent climate change that could worsen the livelihood of the people and the loss of local traditional knowledge systems concerning wise use of forests (Thomas *et al.*, 2004). Endiras natural forest is a dry evergreen afromontane forest that is located in Fogera district which was not investigated so far.

1.3. Significance of the Study

The research was concerned with the floristic composition and structural analysis of woody plant species in Endiras natural forest, Fogera district, Ethiopia. This study would be important to the

society, the Woreda agricultural office, governmental and non-governmental organizations working on the issue. Thus, this research is significant to:

- Provide valuable information about floristic composition, structural analysis of woody plant species and the regeneration status of the forest.
- Develop strategies for reclamation, rehabilitation and restoration by the societies, agricultural office, environment, forest and wild life authority, forest research institute and other concerned bodies for physical recovery of the forest.
- Give base line information for researchers to investigate on other aspects of the forest.

1.4. Research Questions

The following research questions were answered at the end of the research.

- What are the compositions of woody plant species in the study area?
- What are the major woody plant communities in the study area?
- How is the woody species diversity of different community types in the study area?
- What are the structural patterns of woody plant species in the study area?
- What will be the current regeneration status of woody plant species of the study area?
- What are the types of environmental factors significantly affecting species composition and their distribution in the study area?

1.5. Objectives of the Study

The general and specific objectives of the research respectively were as follows:

1.5.1. General objective

The general objective of this study was to document on the floristic composition and structural analysis of woody plant species in Endiras natural forest, Fogera district, Ethiopia.

1.5.2. Specific objectives

The specific objectives of this thesis were:

- To identify and document woody plant species composition of Endiras natural forest;
- To classify the vegetation of woody plants species in to different community types;

- To estimate the woody species diversity of different community types in Endiras natural forest;
- To analyze the population structure of selected species of Endiras natural forest;
- To determine the regeneration status of woody plant species of Endiras natural forest;
- To assess the environmental factors and their correlation on the distribution of woody plant species.

2. LITERATURE REVIEW

2.1. Floristic Diversity

Ethiopia is one of the centers of plant genetic diversity, and that its indigenous forests have been storehouse of biodiversity together with microorganisms, fungi, soil fauna and flora, medicinal plants, wild animals, birds, insects, as well as human beings (Legesse Negash, 2002). The flora of Ethiopia and Eritrea includes about 6027 species of which about 647 (10.74%) are endemic to the flora area (Ensermu Kelbessa and Sebsebe Demissew, 2014).

2.2. Vegetation Types of Ethiopia

Vegetation refers to an assemblage of plants growing together in a particular location, or the collective plant cover of an area (Jennings *et al.*, 2003). Information on the vegetation helps to solve ecological problems for biological conservation and management purposes; as an input to environmental impact assessment; to monitor management practices or to provide the basis for prediction of possible future changes (Kent and Coker, 1992). Friis *et al.* (2011) pointed out that there are twelve major vegetation types in Ethiopia. These major vegetation types include: 1) desert and semi-desert scrubland; 2) *Acacia-Commiphora* woodland and bush land; 3) wooded grassland of the western Gambela region; 4) *Combretum-Terminalia* woodland and wooded grassland, 5) dry evergreen afro-montane forest and grassland complex, 6) moist evergreen afro-montane forest and bush land, 7) transitional rain forest, 8) ericaceous belt, 9) afro-alpine belt, 10) riverine vegetation, 11) fresh - water lakes and 12) salt lakes vegetation.

Dry Evergreen Afro-montane Forest and grassland complex

This vegetation type includes a large number of endemics (Sebsebe Demissew, 1998) and the vegetation is represented by a complex system of successions involving extensive grasslands rich in legumes, shrubs and small to large-sized trees to closed forest with a canopy of several strata. It occurs in an altitudinal range of 1800-3000 m, with average annual temperature and rainfall of 14-45 °C and 700-1100 mm (rarely up to 1700 mm), respectively (Friis *et al.*, 2010).

This ecosystem covers much of highland areas and mountainous chains of Ethiopia in Oromia Region (Shewa, Arsi, northern Bale and western Hararge), Amhara region (Gojam, Wello, and

Gonder), Tigray region (Tigray) and SNNP region (Shewa, Sidamo and Gamo Gofa) (NBSAP, 2005). The common trees species include, *Juniperus procera*, *Olea europaea* subsp. *cuspidata*, *Euphorbia ampliphylla*, *Mimusops kummel* and *Ekebergia capensis*; shrubs including *Dracaena* species, *Carissa spinarum* and *Rosa abyssinica*. The important grass species belong to the genera *Hyparrhenia*, *Eragrostis*, *Panicum*, *Sporobolus*, *Eleusine*, *Pennisetum* and legumes include *Trifolium*, *Eriosema* and *Crotalaria*. The forests in this vegetation types have greatly diminished due to expansion of agriculture and other interference by people and domestic animals and have been replaced by bush land and scrub in most areas (Zewde Achiso, 2014).

Tropical dry forests are among the most exploited forest ecosystems of the world and have been increasingly fragmented (Cabin *et al.*, 2002). The fragmentation results in small stands of forest bordered by open, often agricultural lands (Fleury and Galetti, 2004). Under the increasing pressure by the human population, e.g. grazing activities or tree harvesting, natural regeneration may be hampered and, as a result, the persistence of the remnant forest patches and their indigenous species in many areas are threatened. This is particularly the case in the rapidly developing tropical areas such as in Ethiopia (Cotler and Ortega Larrocea, 2006). Dry afro-montane forests of Ethiopia have faced vast exploitation and almost all these forests have been converted to agricultural lands (Tesfaye *et al.*, 2013), except for small fragments that are left in the most inaccessible areas or around churches (“Church forests”) (Alemayehu Wassie *et al.*, 2005). The disappearance of the forests has been most drastic during the past 100 years. In the beginning of the 1900s, the forested area of the country was estimated at about 40% (EFAP, 1994) but now down scaled to 4.2 % of the land area (FAO, 2001).

2.3. Plant Community Types

Plant community is defined as the collection of plant species growing together in a particular location that show a definite association or affinity with each other (Kent and Cooker, 1992). Certain species are found growing together in certain locations and environments more frequently than would be expected by chance. This is because they have similar requirements for existence in terms of environmental factors such as light, temperature, water, drainage and soil. Mueller-Dombois and Ellenberg (1974) referred a plant community as combination of plants that are dependent on their environment, influence one another, and modify their environment. As

stated in Mueller-Dombois and Ellenberg (1974) the floristic composition of vegetation includes all species occurring within a plant community. However, most plant communities consist of many different species which are not particular to discover all species within a community. Hence, it is common to use the dominant species in naming plant communities (Kent and Cooker, 1992). Information on plant population structure analysis helps to respect the healthy regeneration of the tree species underutilization. It indicates the history of forest disturbances to that species and environment and hence used to forecast the further trend of the population of that particular species (Peters, 1996).

2.4. Diversity Indices

Biological diversity can be quantified in different ways. A diversity index is a mathematical measure of species diversity in a community. The two main factors taken into account when measuring diversity are richness and evenness. So that diversity index, must be sensitive to both factors, thus must also be sensitive to the different number of species in two or more communities (Mueller-Dombois and Ellenberg, 1974).

2.4.1. Species diversity and richness

Species diversity can be viewed from different perspectives: alpha, beta and gamma diversity. Alpha diversity refers to the diversity of species within a particular habitat or community. Beta diversity is a measure of the rate and extent of change in species along a gradient from one habitat to another. It is between habitat diversity that measures turnover rates. Beta diversity is sometimes called habitat diversity (Kent and Coker, 1992). Gamma diversity is the diversity of species in comparable habitats along geographical transect and it depends on the alpha and beta diversity (Kent and Coker, 1992). Moreover, these diversity indices provide information about community composition. Wellbeing of ecological systems can be measured by community diversity indices. Among many of the species diversity indices, diversity and evenness are often calculated by using Shannon diversity index (Kent and Coker, 1992). It is the most widely used index because of its power to combine species richness with evenness better than other indices.

Species richness refers to the total number of species in a community while evenness is the relative abundance of species within the sample or community (Kent and Coker, 1992). The two components can be examined independently or combined in some form of index. Generally,

these patterns of plant species diversity have often been noted for prioritizing conservation activities because they reflect the underlying ecological processes that are important for management (Lovett *et al.* 2000).

2.4.2. Measurement of similarity and dissimilarity

The notion of community resemblance is central in ecology, and it can be obtained by measuring similarity or dissimilarity of the community (Westhoff and van der Maarel, 1978). Similarity indices measure the degree to which the species composition in samples is alike; whereas dissimilarity coefficient assesses which of the two samples differ in composition. Jaccard's similarity index will be used to determine the pattern of species turnover among successive communities and to compare the forest with other similar forests in the country. It is described using the following formula (Kent and Coker, 1992). $J_s = a / (a+b+c)$. Where,

J_s = Jaccard's similarity coefficient;

a = Number of species common to both samples;

b = Number of species found only in sample 1;

c = Number of species found only in sample 2.

2.5. Species Abundance and Frequency

Abundance is the number of individual plants of a given species per unit area. It can be used to show spatial distribution and ranges over time (spatio-temporal variation of species). Frequency is the proportion of quadrats in which a species occurs. It is a measure of the occurrence of a given species in a given area. Frequency indicates how the species are dispersed and is an ecologically meaningful parameter. According to Kent and Coker (1992), it can give an approximate indication of the homogeneity of the quadrats under consideration.

2.6. Importance Value Index (IVI) and Dominance

Plant species vary in their responses to environmental factors. A given species will have a unique set of tolerances to environmental variables, such as disturbance, pH, Altitude, light, soil texture temperature, moisture, and nutrients. At the community level, these differences in tolerances will cause various species to have competitive advantages, depending on the nature of those environmental factors. Therefore, species importance value index permits a comparison of species in a given location and reflects the dominance, occurrence and abundance of a given

species in relation to other associated species in an area (Kent and Coker, 1992). Generally, to develop conservation strategy and plan, species importance value index is a good index for summarizing vegetation characteristics and to rank species for management and conservation practices and to prioritize them.

2.7. Endemism of Plant Species

Endemism is the ecological state of a species being unique to a defined geographic location, such as an island, country or other defined zone, or habitat type. Furthermore, endemic plants are foundations of the native ecosystems or natural communities (Deemson, 2011). Different factors can contribute to endemism. These include physical, climatic and biological factors. According to Deemson (2011), endemics can easily become endangered or extinct if their restricted habitat changes, particularly due to the actions of man, including the introduction of new organisms. Ethiopia is an important regional center of biological diversity and the flora and fauna have rich endemic elements (WCMC, 1992). The country has the fifth largest flora in tropical Africa (Eshetu Yirdaw, 2001). The great diversity of ecological conditions mainly determined by topography has created environments conducive for the development of a wide variety of flora (EPA, 1997). Endemism is particularly high in the Afroalpine vegetation zone and in the dry Montane forest and grassland complex of the plateau (EWNHS, 1996). In general, the afroalpine region is one of the seven centers of endemism of the afrotropical realm (Hurni, 1988).

2.8. Biodiversity and Threats to Ethiopian Vegetation

Biological diversity means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (CBD, 1992). Convention on Biological Diversity (CBD) offers a major opportunity to safeguard and conserve the biological capital at global and regional level. Biodiversity provides free of charge services worth hundreds of billions of Ethiopian Birr every year that are crucial to the well-being of Ethiopia's society and Ethiopia still has a rich diversity vital to the world in both domesticated and wild plant and animal species that occur in variable and unique micro and macro-ecosystems (NBSAP, 2005). Biodiversity plays a key role in ecosystem functioning and has been widely

used as an indicator of ecosystem health (FAO, 2005). For instance, some keystone species are habitat for different organism and important role in the recycling of nutrient (nitrogen, carbon and phosphorous) and stable environment. Humans benefit from and, in many cases, are reliant upon forests for supporting (nutrient cycling, soil formation etc.), Provisioning (food, fresh water, wood, fiber and fuel, etc.), Regulating (climate regulation, flood regulation, disease regulation, water purification, etc.), and cultural (aesthetic, spiritual, educational, recreational value (FAO, 2005).

Although biodiversity is key factor for the sustainability of life, its loss is one of the greatest environmental crises. The growing human population and the consequent rising demand for natural resources have put great pressure on the biodiversity wealth of the world through deforestation, habitat fragmentation and overexploitation of species (Reyers, 2004). Habitat loss and change, over-harvesting, pollution, and climate change have been the direct causes of global biodiversity loss (Ramirez *et al.*, 2001). Besides these global factors, lack of technical knowledge and awareness and political instability have exacerbated the problem in many developing countries (Reyers, 2004).

Ethiopia is one of the developing countries where loss in biodiversity due to degradation of environmental resources is the most serious. Biodiversity resources along with their habitats are rapidly disappearing in many parts the country (Demel Teketay, 1992; Tadesse Woldemariam and Demel Teketay, 2001). This loss in biodiversity ultimately results in economic losses of the country, including reduction in the quantity of carbon that can be sequestered from the atmosphere (EFAP, 1994). Therefore, recognition of these threats to biodiversity has led to draw conservation strategies at global, regional and national levels.

2.9. Regeneration Pattern and Population Structure of Woody Plants

Analysis of population structures, using the size-class distribution of diameter at breast height (DBH) and height of trees and density of naturally regenerated woody species, can provide an insight into their regeneration status (Silvertown and Doust, 1993). Plant population structure shows whether or not the population has a stable distribution that allows continuous regeneration to take place. Plant population structure may change due to changes in recruitment of individuals at low diameter size classes or exploitation of individual at high size classes or throughout the

class size structure. The population structural change is the function of regeneration pattern of individuals within the community. If regeneration was taking place continuously, then, the distribution of species would show reverse J shape structure, which is an indicator of healthy/good regeneration (Demel Teketay, 1997), and it is common in natural forests where external disturbances are minimum (Feyera Senbeta, 2006; Getachew Tesfaye *et al.*, 2010). Any population structural pattern differed from inverted J-shape (e.g. U-shape, J-shape and bell shape) have been attributed to disturbed forests (Poorter *et al.*, 1996).

The variation in relative abundances of size classes and population structure of species were the result of past and present disturbance as well as management history of the forest. Based on the intensity of disturbances woody species show variation in population structure pattern reflected through differences in the abundance of different size classes (Demel Teketay and Granstrom, 1997). Ecologically, there is coexistence of individuals both with small and large size classes among successional associations unless disturbance has occurred. Thus, size class distribution of woody species is a good indication of the impact of disturbance and the forest successional trends (Mligo and Rocky, 2012). Such information is valuable for the understanding of conservation needs of forest ecosystems.

Several studies in Ethiopia have shown variations in population structure and regeneration pattern in forest tree species that has been attributed to different levels of disturbance of forest species (Feyera Senbeta, 2006). Successfully regenerating plant species are characterized by the presence of a sufficient number of individuals at both lower (seedling and sapling) and higher size classes including the reproductive individual trees that are capable of contributing a significant number of viable seeds (Mligo and Rocky, 2012). Lack of individuals at low size classes and mature reproductive individuals may be related to their regeneration failure in combination with over-exploitation for poles, firewood, charcoal burning and timber extraction. Selective cutting of matured trees leaving out the few stunted and genetically poor individuals causes population decline (Lyaru *et al.*, 2000).

Active regeneration could have been influenced by the presence of relatively abundant reproductive mature trees scattered in the forest. However, poor seedling densities might be caused by intensive exploitation of mature reproductive individuals (Mligo and Rocky, 2012).

Seedling densities in forest understoreys are dynamic and rates may vary among species in gap and shade environments (Bazzaz, 1991). The rates also vary due to mortality, drought and biotic factors such as herbivore, disease or competition (Augspurger, 1984). Understanding tree seedling ecology can provide alternatives for forest development by improving the recruitment, establishment and growth of the desired species (Swaine, 1996). Therefore, regeneration studies have major roles in the management, conservation and restoration of degraded natural forests.

2.10. Properties of soil in Ethiopia

The soils of the Ethiopian highlands are highly variable, varying greatly in their inherent natural characteristics and productive capacities. This is attributed to the extremely rugged terrain, widely varying topography and mountainous landscape which further govern the variations in regional geomorphologies, soil parent materials, soil toposequences, agroecological zones (climate), land use and types of plant and animal lives in a given area. As a result, many soil types differing from each other in their morphological, physical, chemical, mineralogical, and biological properties occur on a given landscape along a toposequence (Mohammed *et al.*, 2005). The fertility, water holding capacity, susceptibility to erosion and potential productivity of these soil types differ from each other significantly. It helps to determine the types of vegetation and land use best suited to a location (Globe, 2005).

2.10.1. Soil physical properties

Soil physical properties largely used to determine the soil's water and air supplying capacity to plants.

Soil texture

Soil texture determines a number of physical and chemical properties of soils. It affects the infiltration and retention of water, soil aeration, absorption of nutrients, microbial activities, (Gupta, 2004). It is also an indicator of some other related soil features such as type of parent material, homogeneity and heterogeneity within the profile, migration of clay and intensity of weathering of soil material or age of soil (Lilienfein *et al.*, 2000). Soil texture is one of the inherent soil physical properties less affected by management. The rate of increase in stickiness or ability to mould as the moisture content increases depend on the content of silt and clay, the

degree to which the clay particles are bound together into stable granules and the OM content of the soil (White, 1997).

2. 10. 2. Soil chemical properties

Soil chemical properties are the most important among the factors that determine the nutrient supplying power of the soil to the plants and microbes. The chemical reactions that occur in the soil affect processes leading to soil development and soil fertility build up. Minerals inherited from the soil parent materials overtime release chemical elements that undergo various changes and transformations within the soil.

2. 10. 2. 1. Soil reaction (pH) and electrical conductivity

Soil reaction (usually expressed as pH value) is the degree of soil acidity or alkalinity, which is caused by particular chemical, mineralogical and/or biological environment. Soil reaction affects nutrient availability and toxicity, microbial activity, and root growth. Thus, it is one of the most important chemical characteristics of the soil solution because both higher plants and microorganisms respond so markedly to their chemical environment. Electrical conductivity (EC) is a measure of salinity. In addition to overcoming some of the ambiguities of total dissolved salts measurements, the EC measurement is quicker and sufficiently accurate for most purposes (Bohn *et al.*, 2001).

2. 10. 2. 2. Cation exchange capacity

The Cation exchange capacity (CEC) of soils is defined as the capacity of soils to adsorb and exchange cations (Brady and Weil, 2002). Cation exchange capacity is an important parameter of soil because it gives an indication of the type of clay minerals present in the soil, its capacity to retain nutrients against leaching and assessing their fertility and environmental behavior. Generally, the chemical activity of the soil depends on its CEC.

2. 10. 2. 3. Soil organic matter

Soil OM is defined as any living or dead plant and animal materials in the soil and it comprises a wide range of organic species such as humus substances, carbohydrates, proteins, and plant residues (Foth and Ellis, 1997). Humus is the substance left after soil organisms have modified

original organic materials to a rather stable group of decay products as is the colloidal remains of OM (Millar and Donahue, 1995). Foth (1990) has indicated that the distribution of OM, expressed as organic carbon, is 38% in trees and ground cover, 9% in the forest floor and 53% is in the soil including the roots plus the OM associated with soil particles.

2. 10. 2. 4. Total nitrogen

Nitrogen (N) is the fourth plant nutrient taken up by plants in greatest quantity next to carbon, oxygen and hydrogen, but it is one of the most deficient elements in the tropics for crop production (Mesfin Abebe, 1998). The total N content of a soil is directly associated with its OC content and its amount on cultivated soils is between 0.03% and 0.04% by weight (Tisdale *et al.*, 1995).

2. 10. 2. 5. Available phosphorus

Following N, P has more wide spread influence on both natural and agricultural ecosystems than any other essential elements. In most natural ecosystems, such as forests and grasslands, P uptake by plants is constrained by both the low total quantity of the element in the soil and by very low solubility of the scarce quantity that is present (Brady and Weil, 2002).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

The research was conducted in Endiras Forest which occurs 7.1 km straight distance to south east of Woreta town in Fogera district, South Gondar Zone of the Amhara Region. The grid reference of the Forest is 11°52'N, 037°044'E and an elevation ranges from 1968 to 2064 meters above sea level. Woreta is found 625 km from Addis Ababa and 55 km from the regional capital, Bahir Dar (Figure 1).

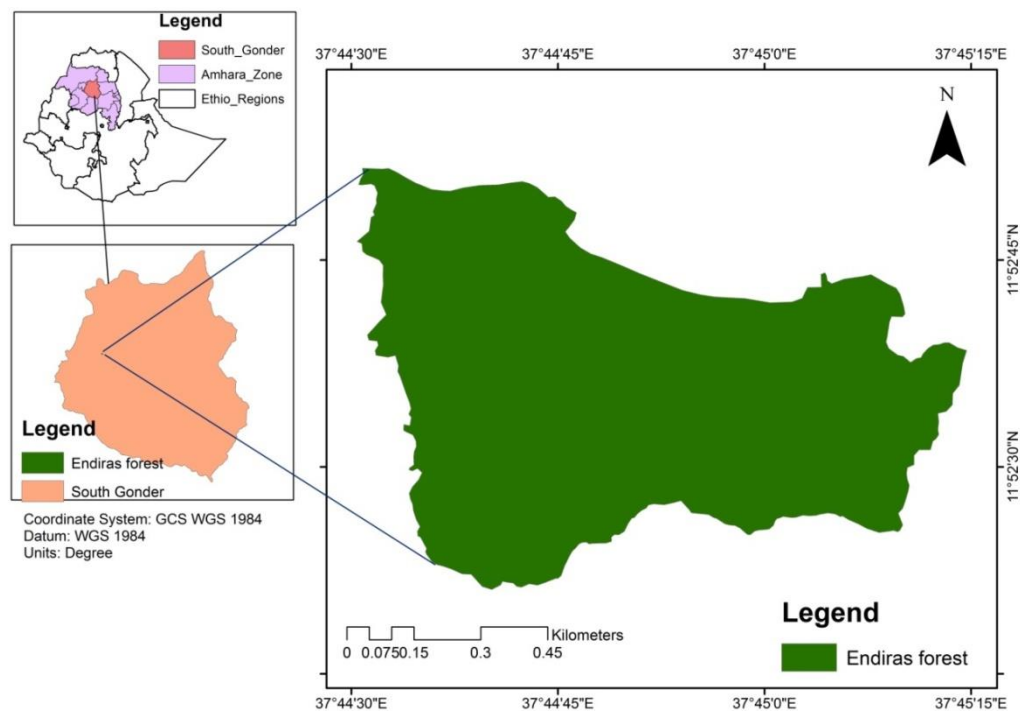


Figure 1: Map of Ethiopia and location map of the study area

3.1.2. Topography

The altitude of Fogera district range from 1700 to 2400 m.a.s.l and topographically; the flat area accounts for 76%, mountain and hills 11% and the valley bottom are 13%. There are two rivers, namely Rib and Gumara which are the main source of irrigation during dry season for the people near the forest (Anjulo and Mezgebu, 2006).

3.1.3. Demographics

According to data obtained from the Central Statistical Agency (CSA, 2015), the total population of Fogera district was 228,449 of which 116, 46 (50.98%) were males and 111,984 (49.02%) were females. From the total population 203,259 (88.97%) were living in rural areas whereas 25,190 (11.02%) were living in urban.

3.1.4. Temperature and rainfall

The temperature and rainfall data for this study was obtained from Amhara Metrological Service Center from 2010 to 2019. The climate diagram was computed by using R graphics for windows version 4.0.1. The area has uni-modal rainfall distribution pattern. The climate of the study area was illustrated based on 10 year data. The mean annual rainfall in the study area was about 1401mm, the rainfall peak period was from July to October and decreasing from November to December, and no rainfall or little from January to May. The mean annual temperature was about 21°C and the mean minimum and maximum temperatures of the area were 13.5°C and 29.8°C respectively (Figure 2).

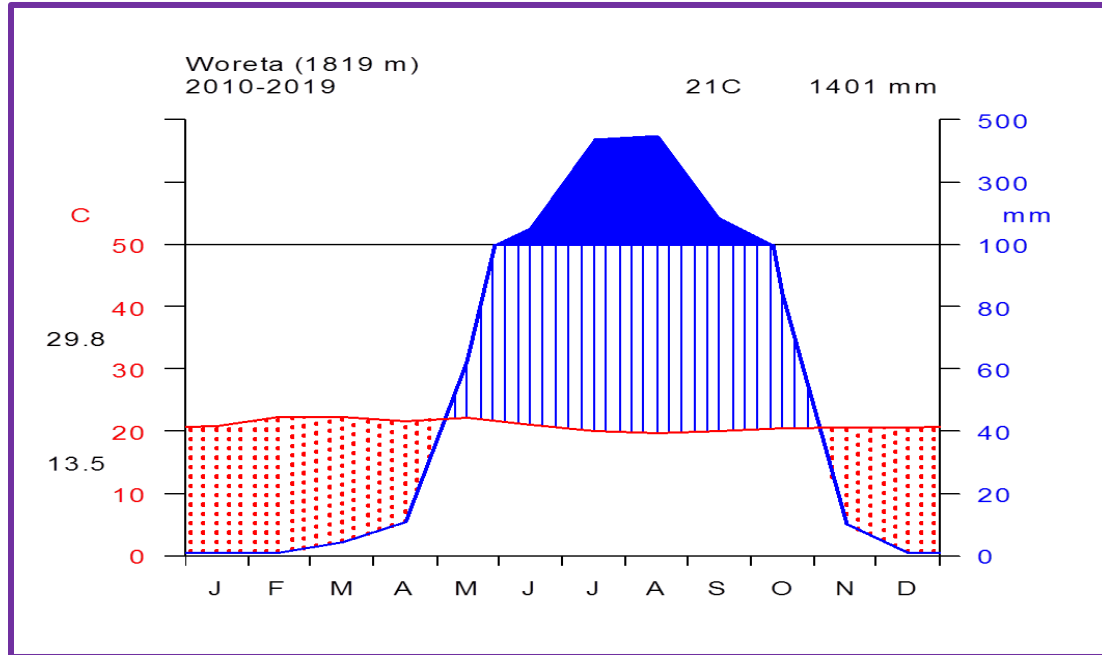


Figure 2: Climate diagram for Woreta town showing rainfall distribution and temperature variation from 2010 to 2019. [Data source: Amhara Meteorological Service Center (AMSC, 2020)].

3.2. Materials

The materials that were used during the actual plant data collection in the field were plant press (to press plant specimens), secateurs (to cut plant body parts to be pressed), GPS (to take geographical information such as altitude, latitude and longitude), digital camera (to capture photo during data collection), rolling meter (to measure length of line transect and plots), scotch tape (to stick herbarium levels on plant press), plastic with different size rope (to make line transect and plots), hand lens (to observe trichomes on plant parts), hypsometer (to measure height or elevation), tree caliper (to measure DBH), clinometer and calibrated bamboo stick (to measure the height of woody plants), compass (to measure aspect), soil Auger (to take soil sample) and plastic bags (to hold soil samples).

3.3. Methods of Data Collection

3.3.1. Reconnaissance survey

Reconnaissance survey was made in mid-September, 2019 to have familiarity with the vegetation, topography of the area, take coordinate points and hypothesize vegetation environment relationships such as altitude, slope, aspect and soil. The actual data collection was conducted from November 1, 2019 to January 15, 2020.

3.3.2. Vegetation sampling design

Systematic sampling design was used for this study to collect vegetation data following Mueller-Dombois and Ellenberg (1974) in North-South direction. Line transects were laid at every 100m distance between transects. The first line transect was laid by avoiding the forest edge (at least 50m into the forest) against altitudinal gradients in order to capture representative samples of the forest. Fifty plots having an equal size of 20m x 20m (400m²) were laid out to collect data on woody species. The distance between two consecutive plots along a line transect was 100m. Within the main plot 5m x 5m for seedling and sapling four at the corners and one in the middle were used for data collection.

3.3.3. Floristic data collection

All plant species including trees, shrubs and lianas in each plot were recorded. Additional plant species occurring outside the plots, but inside the forest within 10 m from plots were also

recorded as “present”, but they were not used in the subsequent data analysis (Tamrat Bekele, 1993). The local names of the species were recorded and included in the list of taxa. Growth forms of plants were listed and voucher specimens were collected. Specimens were dried, numbered, pressed, identified and deposited at the National Herbarium (ETH) in Addis Ababa University (AAU). Identification of specimens was performed using recognition method in the field, expert determination and comparison with authenticated herbarium specimens at the national herbarium (ETH). The nomenclature of plant specimens was based on Flora of Ethiopia and Eritrea. The percentage cover abundance was estimated and later converted into modified 1-9 Braun-Blanquet scale modified by Van Der Maarel (1979) as shown in (Table 1).

Table 1: Modified Braun-Blanquet scales

Scales	Cover abundance values for each species in percent
1	Rare, generally one individual
2	Occasional, with less than 5% cover
3	Abundant, with less than 5% cover
4	Very abundant, with less than 5% cover
5	5-12% cover
6	2.5-25% cover
7	25.5-50% cover
8	50.5-75% cover
9	Above75% cover

3.3.4. Structural data collection

The tree density, diameter at breast height (DBH), frequency, dominance, basal area and IVI were measured, recorded and used for description of vegetation structure. DBH at 1.3 m of all trees and shrubs having diameter at breast height ≥ 2.5 cm was measured (Figure 3). Trees/Shrubs with multiple stems at 1.3 m height were treated as a single individual and the diameter was measured separately for the branches and averaged as one DBH and the tree/shrub boles buttressed, DBH measurement was undertaken from the point just above the buttresses. Trees with multiple stems or fork below 1.3 m height were also treated as a single individual (Kent and Coker, 1992). Heights of all seedlings (individuals < 60 cm height), saplings (DBH <

2.5 cm and ≥ 60 cm height) and mature trees/shrubs (DBH ≥ 2.5 cm and ≥ 60 cm heights) was recorded (GTZ, 2002). Seedlings and saplings of trees and shrubs were counted to estimate the regeneration status of the forest.



Figure 3: Basal area and height measurements in the field during data collection

3.3.5. Environmental data collection

Terrain variables such as altitude, aspect, slope and geographical coordinates were taken and recorded for each sample plot. Altitude and geographical coordinates were measured using GPS; slope and aspect of each plot was measured using Optical Reading Clinometer and compass, respectively. Values for aspect was codified based on Zerihun Woldu *et al.* (1989), where N = 0, NE = 1, E = 2, SE = 3, S = 4, SW = 3.25, W = 2.5, NW = 1.25 before analysis.

Ecological disturbances such as grazing and impacts of human beings (cutting, collecting firewood and trampling in the vegetation) was noticed and recorded as present or absent in the sampled plots. Grazing intensity was estimated following Zerihun Woldu and Backeus (1991); and Kebrom Tekle *et al.* (1997) as: 0 = nil; 1 = slight; 2 = moderate and 3 = heavy. The state of human interference was estimated following Kumlachew Yeshitla and Tamrat Bekele (2003) and codified using a 0-3 subjective scale to record the degree of the impacts (from cutting, fuel wood collection and sign of trampling) as: 0 = nil; 1 = low; 2 = moderate; and 3 = heavy.

Soil samples were taken from each sample plot 0-50 cm using soil Augur. A kilogram of soil sample from five points were taken and mixed to form a composite sample in order to reduce variability within the sample plots 15 x 15 cm², one at the center and the other four at each corner of each sample plot (Eyob Tenkir, 2006). A total of 10 soil samples two from each community, one from lower altitude (1972-1997) and other from upper altitude (2000-2064) were taken, air-dried, put in plastic bag, wrapped and transported to Amhara design and supervision works enterprise laboratory service (soil chemistry and quality section). Analysis of soil texture (clay, sand and silt), organic matter (OM), acidity/alkalinity (pH), Electrical conductivity (EC), total nitrogen (N), exchangeable cations (Ca, Mg, K, and Na), cation exchange capacity (CEC) and available phosphorus (P) were determined following the standard procedures outlined in ISRIC (2002) as shown in (Table 2).

Table 2: The methods used to analyze the soil physical and chemical properties

Soil physical/chemical parameters		Methods used
Texture class (sand, clay and silt)		Hydrometer method
Exchangeable cations	Ca and Mg	Atomic Absorption Spectrophotometer (AAS)
	Na and K	Flame Emission Spectrophotometer (FES)
Electrical conductivity		Ammonium acetate (Nh ₄ OAc)
Cation exchange capacity		
Organic Carbon		Walkley-Black method
Organic matter content		
Soil pH		PH meter at 1:2.5 soil- distilled water suspension
Total Nitrogen		Wet- oxidation (wet digestion)
Available phosphorous		Olson method

3.4. Method of Data Analysis

3.4.1. Floristic data analysis

Hierarchical cluster analysis is one of the most commonly used multivariate techniques to analyze community ecological data. It helps to group a set of observations (vegetation samples) together, based on their attributes or floristic similarities (Kent and Coker, 1992). For this study, agglomerative hierarchical classification for cluster analysis using similarity ratio as resemblance

index and Ward's Method as clustering technique was performed by using appropriate R programs developed by Zerihun Woldu (2014).

3.4.2. Diversity and similarity indices

Biological diversity can be quantified in different ways (Colwell and Lees, 2000). Shannon-Wiener diversity index is the most popular measure of species diversity, because it accounts both for species richness and evenness, and this Shannon-Wiener diversity index is not affected by sample size (Kent and Coker, 1992). Therefore, Shannon-Wiener diversity index, species richness and Shannon's evenness are computed to describe the diversity of the community types identified. These, Shannon-Wiener diversity index was calculated as follows:

$$H' = - \sum_{i=1}^S p_i \ln p_i$$

- H' = Shannon Diversity Index,
- S = the number of species,
- P_i = the proportion of individuals or the abundance of the i^{th} species expressed as a proportion of total cover and
- $\ln$ = log base_e
- ❖ Evenness (Equitability) $J = H' / H' \text{ max}$, where;
- J = Evenness,
- H' = Shannon-Wiener diversity index and
- $H' \text{ max} = \ln s$ where s is the number of species.

Jaccard's similarity index was used to determine the pattern of species turnover among successive communities and to compare the forest with other similar forests in the country. It is described using the following formula (Kent and Coker, 1992). $J_s = a / (a+b+c)$. Where,

J_s = Jaccard's similarity coefficient;

a = Number of species common to both samples;

b = Number of species found only in sample 1;

c = Number of species found only in sample 2.

3.4.3. Structural data analysis

The structure of woody species of the forest was described through the analysis of species density, Diameter at Breast Height, height, basal area and frequency. The Diameter at Breast Height (DBH) was categorized into seven DBH classes; 2.5-5 cm, 5.1-10 cm, 10.1-15 cm, 15.1-20 cm, 20.1-30 cm, >40 cm (Sosina Hailu, 2016) and the number of individuals in each class was calculated. Vertical stratification structure of the woody species was analyzed using the International Union for Forestry Research Organization (IUFRO) classification scheme (Lamprecht, 1989). According to its height three vertical structures were recognized. These were upper storey (tree height > 2/3 of the top height), middle storey (tree height between 1/3 and 2/3 of the top height) and lower storey (<1/3 of the top height). Besides tree height was categorized into seven height classes; 2.5-5 m, 5.1-10 m, 10.1-15 m, 15.1-20 m, 20.1-25 m, 25.1-30 m, >30 m and the percentage number of individuals in each class was calculated (Sosina Hailu, 2016). Other vegetation data were computed and summarized on Microsoft Office Excel 2010 spreadsheet using the following formula:

A. Frequency: It is obtained by using plots and expressed as the number of plots in which a species was recorded per total number of plots as a percentage (Goldsmith *et al.*, 1986).

$$\text{Relative frequency (Rf)} = \frac{\text{the number of plots where which that species occurs}}{\text{total number of plots}} \times 100$$

B. Density: It can be used to show spatial distribution and ranges over time. Afterwards, the sum of individuals per species in all quadrats is calculated in terms of species density per convenient area unit such as a hectare (Mueller-Dombois and Ellenberg, 1974).

$$\text{Density (D)} = \frac{\text{number of above ground stems of species counted}}{\text{sample area by ha}}$$

C. Basal Area (BA): Is the area outline of a plant near ground surface. In trees, it is measured through diameter at breast height (DBH), i.e., 1.3 m above ground level on the uphill side of a tree (Muller Dombois and Ellenberg, 1974). Basal area is also used to calculate the dominance of species. $BA = \pi (D/2)^2 = (DBH/2)^2 \times 3.14$, where D or DBH is diameter at breast height measured in meter.

D. Importance Value Index: IVI Analysis is used for setting conservation priority. Those species which receive lower IVI values need high conservation efforts while those with higher IVI values need monitoring Management. It combines data for three parameters relative frequency, relative density and relative abundance Kent and Coker (1992).

$$IVI = RD + RF + RDO$$

$$\text{Relative Density of a species (RD)} = \frac{\text{Number of all individuals of a species}}{\text{Total number of all individuals of the sample}} \times 100$$

$$\text{Relative Frequency of a species (RF)} = \frac{\text{The number of plots where a species occur}}{\text{Total occurrence for all species of the sample}} \times 100$$

$$\text{Relative Dominance of a species (RDO)} = \frac{\text{Basal area of a species}}{\text{Total basal area of the sample}} \times 100$$

Based on IVI values tree species were grouped in to 5 classes for conservation priority following Simon Shibru and Girma Balcha (2004). Where: 1) >15, 2) 10.01-15, 3) 5.01-10, 4) 1.01-5, 5) ≤1.

3.4.4. Regeneration data analysis

The regeneration status of sample species in the forest was analyzed by comparing seedling with saplings and saplings with matured trees data in the following categories following Keflay Gebrehiwot and Kitessa Hundera (2014). 1) “good” regeneration, if present in seedling > sapling > mature tree; 2) “fair” regeneration, if present in seedling > sapling < mature tree; 3) “poor” regeneration, if a species survives only in the sapling stage, but not as seedlings (even though saplings may be less than, more than, or equal to mature); 4) “none”, if a species is absent both in sapling and seedling stages, but present as mature; and 5) “new”, if a species has no mature, but only sapling and/or seedling stages. To use the regeneration analysis for priority setting, woody plant species considered in the study area were classified into three groups based on the density of seedling following Shiferaw Belachew (2010). Accordingly, those species totally absent and those that are represented only as one seedling individual in the regeneration were grouped under Group 1; others whose density were greater than one but less than fifteen were grouped under Group 2, and remaining are grouped under the third

3.4.5. Environmental data analysis

Canonical Correspondence Analysis (CCA) was applied as a direct ordination method using the vegetation data and environmental data collected. The resulting ordination diagram expresses not only patterns of variation in floristic composition but also demonstrates the principal relationships between the species and each of the environmental variables (Kent, 2012). The analysis was conducted using the free statistical software R graphics version 4.0.1. (R: Development Core Team, 2014). Before the CCA analysis, forward and backward stepwise selection of environmental variables was carried out to identify variables that could significantly explain the variability of species or plant community distributions. This was based on the assumption that the large majority of the explanatory variables may add little to the explanation since many of them were collinear (significantly correlated to each other) (Zerihun Woldu, 2014).

4. RESULTS

4.1. Species Accumulation Curve

In ecological communities, the number of species increases with increasing area sampled. However, the rate of newly added species decreases with increasing sampling effort. This trend of species accumulation in the sampling effort could be represented graphically using species accumulation curve. The graph was plotted for the cumulative number of species recorded as a function of sampling effort. Species accumulation curve helps to illustrate the rate at which new species are included as the sampling effort proceed. One of its applications is to assess whether a study area has been sufficiently sampled or not. A curve levels off (or approximately reaching an asymptote) indicating that no or few species would be collected if sampling effort was further continued. Accordingly, as it is indicated in (figure 4), the curve almost leveled off showing that a few species would be collected if sampling effort was further continued. This could prove that representative samples have been taken in the study area.

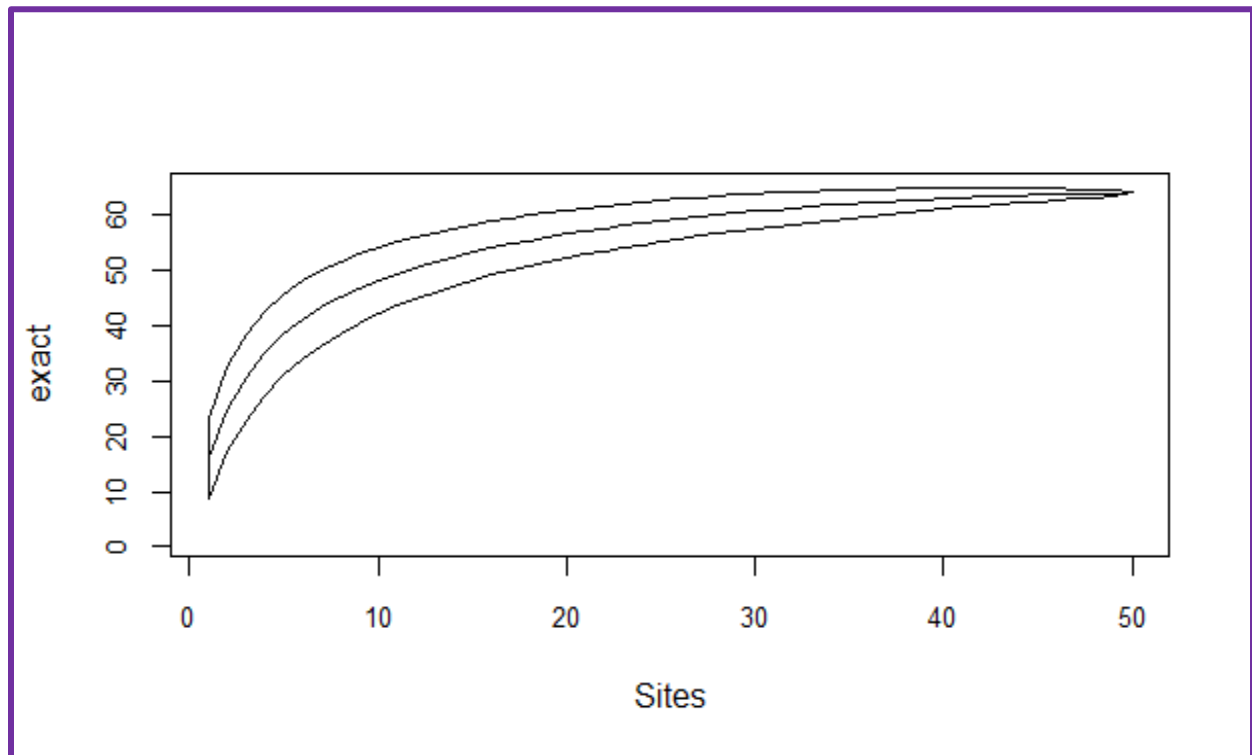


Figure 4: Species accumulation curve for Endiras forest

4.2. Floristic Composition of the Study Area

A total of 69 woody plant species in 57 genera and 36 families were identified from the study area (Appendix 1). Out of which, 64 species were identified to species level and five to sub species level. The major families were Fabaceae contributed fifteen (22.06%) species; Euphorbiaceae and Moraceae had four species each (contributed 5.88%) each, Lamiaceae and Myrsinaceae had three species (4.41%) each, while nine families Acanthaceae, Apocynaceae, Asteraceae, Celastraceae, Combretaceae, Pittosporaceae, Sapindaceae, Flacourtiaceae and Oleaceae had two species (2.94%) each and the remaining twenty two families were represented by one species (1.47 %) each.

In Endiras Forest the top fourteen species rich families comprise 69.12% (47 species) of the recorded species (Table 3). However, 22 of the families (22 species) recorded in this forest comprising 30.88% of the total species (Table 3).

Table 3: Families with two or more species in Endiras Forest

S.No.	Family	No. of species	Species percentage
1	Fabaceae	15	22.06
2	Euphorbiaceae	4	5.88
3	Moraceae	4	5.88
4	Lamiaceae	3	4.41
5	Myrsinaceae	3	4.41
6	Acanthaceae	2	2.94
7	Apocynaceae	2	2.94
8	Asteraceae	2	2.94
9	Celastraceae	2	2.94
10	Combretaceae	2	2.94
11	Oleaceae	2	2.94
12	Pittosporaceae	2	2.94
13	Sapindaceae	2	2.94
14	Flacourtiaceae	2	2.94
Total		47	69.12

The cluster analysis of vegetation was based on abundance of species that were collected within the plots. Four species were observed outside the plots in the study area within a range of 10 m distance. These were *Acacia abyssinica*, *Clerodendrum myricoides*, *Piliostigma thonningii* and *Scolopia theifolia*. One species (*Rhamnus prinoides*) was found in the sampled plot but only in

the sapling stage. Among the total species 37 (53.62%) were shrubs, 29(42.03%) were trees and 3 (4.35%) were lianas (Figure 5).

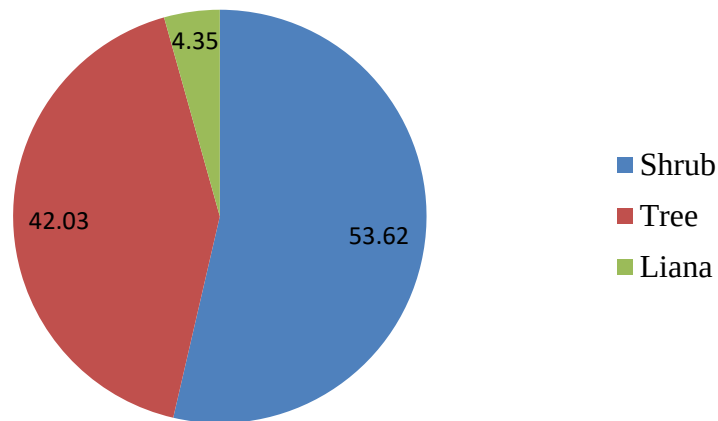


Figure 5: The growth form of plant species in Endiras Forest

4.2.1. Endemic plants in Endiras Forest

Three endemic plant species were revealed in the study area. Two of these species were shrubs and one of the species was tree. These species were distributed into three families and three genera (Table 4). This showed that Endiras Forest was a place where one can find a range of plant species including endemics.

Table 4: List of endemic species and level of threat collected from the study area (Vivero *et al.*, 2005)

No.	Scientific Name	Family	ICN Category	Habit	Distribution
1	<i>Acanthus sennii</i>	Acanthaceae	NT	SH	GD, GJ, WG, SU, HA, AR, BA, KF, GG, SD
2	<i>Millettia ferruginea</i>	Fabaceae	LC	T	WG, SU, HA, BA, IL, KF, SD
3	<i>Rhus glutinosa</i> Subsp. <i>glutinosa</i>	Anacardiaceae	VU	SH	TU, GD, GJ

Note: NT = Near Threatened, LC = Least Concern, VU = Vulnerable

Based on the IUCN level of criteria of threat, one species was least concern (LC), one species was near threatened (NT) and one species was assessed as Vulnerable (VU) (Table 4).

4.2.2. Woody plant communities in Endiras Forest

Cluster analysis showed five different communities (clusters) for Endiras Forest in (Figure 6). The communities were described based on their synoptic cover values (Appendix 3). The following plant communities were named based on the two dominant woody species which have the highest mean cover/abundance that appears within the cluster. A description of the five plant community types were given as follows:

1. *Acacia lahai* - *Carissa spinarum*

This community contained 19 plots and 58 species between the altitudinal range of 1972 and 2016 m.a.s.l (Table 5). The most dominant plant species in this community type were *Acacia lahai* and *Carissa spinarum* (Appendix 3). The tree layer was represented by *Acacia lahai*, *Croton macrostachyus*, *Albizia gummifera*, *Stereospermum kunthianum* and *Erythrina abyssinica*. The shrubs layer was represented by *Acanthus polystachius*, *Bersama abyssinica*, *Calpurnia aurea*, *Capparis tomentosa*, *Carissa spinarum*, *Grewia ferruginea*, *Maytenus undata*, *premna schimperi*, *Pterolobium stellatum*, *Rhus glutinosa*, and *Vernonia myriantha*. The common climbers/ liana were *Jasminum abyssinicum* and *Rhoicissus tridentate*.

2. *Buddleja polystachya* - *Croton macrostachyus*

This community contained 7 plots and 44 species between the altitudinal ranges of 1988 and 2043 m.a.s.l. (Table 5). The most dominant plant species in this community type were *Buddleja polystachya* and *Croton macrostachyus* (Appendix 3). The tree layer was represented by *Croton macrostachyus*, *Ficus sycomorus*, *Millettia ferruginea*, *Acacia senegal*, *Acacia lahai*, *Stereospermum kunthianum*, *Terminalia brownii* and *Combretum collinum*. The shrubs layer was represented by *Calpurnia aurea*, *Bersama abyssinica*, *Rhus glutinosa*, *Maytenus undata* and *Vernonia myriantha*. The common climbers/ liana were *Jasminum abyssinicum* and *Rhoicissus tridentate*.

3. *Syzygium guineense* - *Maytenus undata*

This community contained 19 plots and 42 species between the altitudinal range of 1978 and 2031 m.a.s.l. (Table 5). The most dominant plant species in this community type were *Syzygium guineense* and *Maytenus undata* (Appendix 3). The tree layer was represented by *Syzygium guineense*, *Croton macrostachyus*, *Acacia senegal*, *Acacia lahai*, *Albizia gummifera* and *Ximenia*

americana. The shrubs layer was represented by *Maytenus undata*, *Carissa spinarum*, *Rhus glutinosa*, *Euclea racemosa*, *Osyris quadripartita* and *Rosa abyssinica Turraea*. The common climbers/ liana were *Jasminum abyssinicum* and *Rhoicissus tridentate*.

4. *Osyris quadripartita* - *Pittosporum viridiflorum*

This community contained 6 plots and 38 species between the altitudinal ranges of 1975 and 2059 m.a.s.l. (Table 5). The most dominant plant species in this community type were *Osyris quadripartita* and *Pittosporum viridiflorum* (Appendix 3). The tree layer was represented by *Pittosporum viridiflorum*, *Syzygium guineense*, *Gardenia ternifolia*, *Albizia gummifera*, *Ximenia americana*, *Acacia senegal*, *Acacia lahai* and *Phoenix reclinata*. The shrub was represented by *Osyris quadripartita*, *Rhus glutinosa*, *Carissa spinarum*, *premna schimperi*, *Maytenus undata*, *Dodonea angustifolia* and *Euclea racemosa*. The common climbers/ liana were *Embelia schimperi*, *Jasminum abyssinicum* and *Rhoicissus tridentate*.

5. *Acacia senegal* - *Rhus glutinosa*

This community contained 7 plots and 39 species between the altitudinal ranges of 1984 and 2064 m.a.s.l. (Table 5). The most dominant plant species in this community type were *Acacia senegal* and *Rhus glutinosa* (Appendix 3). The tree layer was represented by *Acacia senegal*, *Croton macrostachyus*, *Gardenia ternifolia*, *Pittosporum viridiflorum*, *Albizia schimperiana*, *Terminalia brownii*, *Ficus vasta*, *Celtis africana*, *Entada abyssinica* and *Stereospermum kunthianum*. The shrub was represented by *Rhus glutinosa*, *senna singueana*, *Dovyalis abyssinica*, *Dichrostachys cinerea*, *Maesa lanceolata*, *Myrsine africana*, *Flueggea virosa* and *Clausena anisata*. The common climbers/ liana were *Entada abyssinica*, *Jasminum abyssinicum* and *Rhoicissus tridentate*.

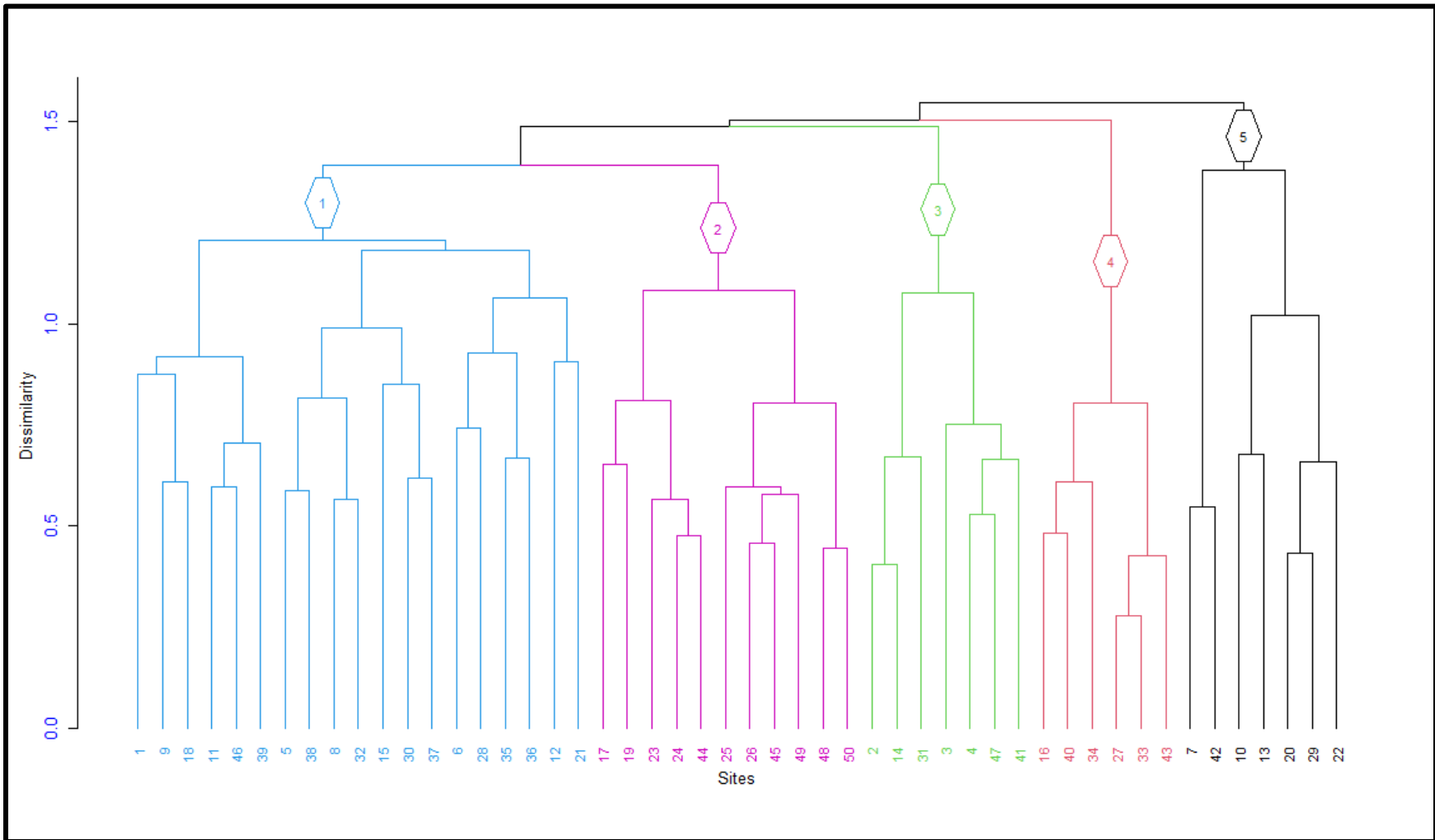


Figure 6: Dendrogram of the vegetation data obtained from hierarchical cluster analysis of vegetation of the study area

Table 5: Plots in the community

Community	Plots number	total plots	Altitude (m.a.s.l)
1	1,9, 18, 11, 46, 39,5, 38, 8, 32, 15, 30, 37, 6, 28, 35, 36, 12, 21	19	1972-2016
2	17, 19, 23, 24, 44, 25, 26, 45, 49, 48, 50	11	1988-2043
3	2, 14, 31, 3, 4, 47, 41	7	1978-2031
4	16, 40, 34, 27, 33, 43	6	1975-2059
5	7, 42, 10, 13, 20, 29, 22	7	1984-2064

4.3. Species Richness, Diversity and Evenness of the Plant Communities

From the computation of vegetation data obtained from the study area, the results of Shannon-Wiener diversity index showed that, community 1 (58 species) had the highest species richness, evenness and diversity. Community 4 showed the lowest species richness, evenness and diversity (Table 6). The overall Shannon–Wiener diversity (H') and evenness (J) of woody species in Endiras Forest were 3.40 and 0.82, respectively.

Table 6: Species richness, diversity and evenness of the communities

Community	Species richness (S)	Diversity index (H')	Shannon Evenness	$H'_{\max} = \ln S$
1	58	3.75	0.92	4.06
2	44	3.25	0.86	1.33
3	47	3.28	0.85	3.85
4	38	3.07	0.84	3.64
5	39	3.13	0.86	3.66
Over all diversity		3.4	0.82	

4.4. Similarity between the Community Types

The Jaccard's similarity coefficient of five communities was shown in (Table 7). Community 1 and 5 had the highest similarity (0.73%), followed by 3 and 4 (0.70%). On the other hand the lowest similarity was observed between communities 2 and 4 (0.56%).

Table 7: Jaccard's similarity coefficient among the 5 communities

Community	1	2	3	4	5
1	1.00				
2	0.65	1.00			
3	0.67	0.61	1.00		
4	0.68	0.56	0.70	1.00	
5	0.73	0.58	0.61	0.62	1.00

4.5. Vegetation Structure of Endiras Forest

4.5.1. Tree and shrub density

The overall density of mature woody species with DBH ≥ 2.5 cm in Endiras Forest was 6505 stems/m² or 3252.5 stems/ha. This was classified into seven density classes: 1) <5 , 2) 5.01 - 20, 3) 20.01 - 35, 4) 35.01-50, 5) 50.01 - 65, 6) 65.01 - 80, 7) > 80 stems ha⁻¹ (Figure 7). Fourteen species (4559 individuals) contributed 70.08 % of the total density from the density class 8 which was due to the dominance of species *Carissa spinarum*, *Maytenus undata*, *Acanthus polystachius*, *Calpurnia aurea*, *Rhus glutinosa*, *Croton macrostachyus*, *Pterolobium stellatum*, *Acanthus sennii*, *Osyris quadripartita*, *Dodonea angustifolia*, *Bersama abyssinica*, *Acacia lahai*, *Grewia ferruginea* and *premna schimperi*. Fifteen species (89 individuals) from density class 1 which was due to *Celtis africana*, *Bridelia micrantha*, *Ficus palmata*, *Acacia persiciflora*, *Sapium ellipticum*, *Ficus vasta*, *Ficus thonningii*, *Hypericum quartinianum*, *Brucea antidysenterica*, *Mimusops kummel*, *Allophylus abyssinicus*, *Vernonia amygdalina*, *Ficus sycomorus*, *Cordia africana* and *Turraea holstii* contributed 1.37% of the total density (Figure 7).

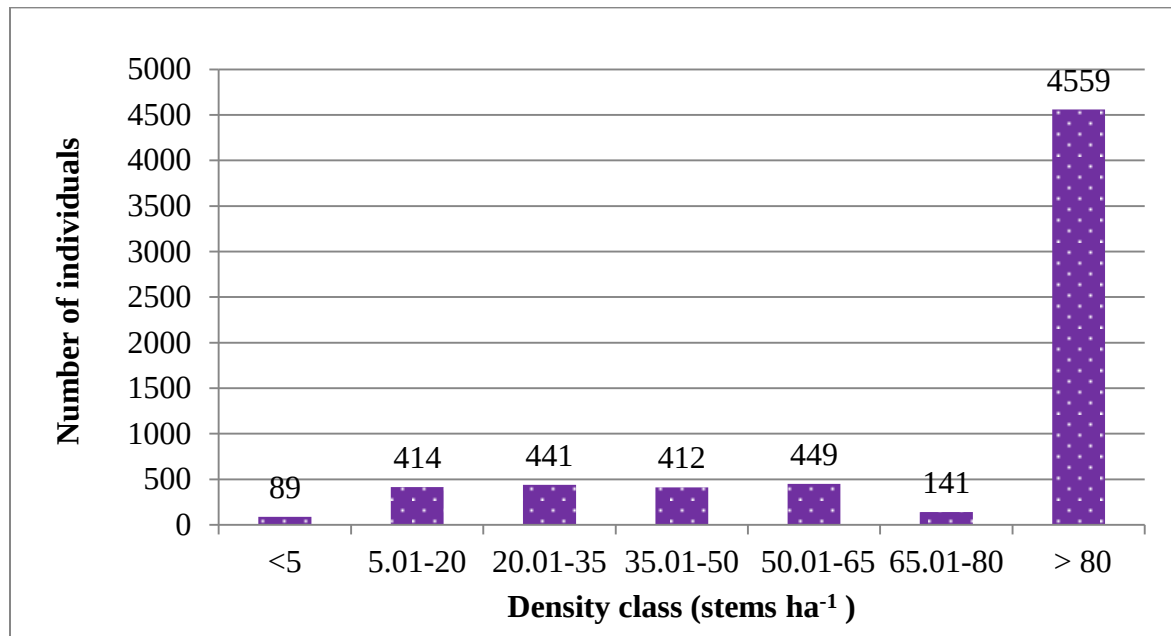


Figure 7: Distribution of individuals in different density classes

4.5.2. Basal area

Total basal area of the vegetation was 31.81 m² or 15.91 m²/ha for woody species ≥ 2.5 cm in DBH and >1.3 m in height. The top five species (*Acacia lahai*, *Rhus glutinosa*, *Croton macrostachyus*, *Syzygium guineense*, *Ficus vasta*) constituted 41.47% of the total basal area while the other 59 species contributed 58.53% of the total basal area as shown in (Table 8).

Table 8: Basal area of the top 5 common woody plant species in Endiras Forest

No.	species	Basal area (m ²)	Basal area (m ² /ha)	percent
1	<i>Acacia lahai</i>	3.30	1.65	10.39
2	<i>Rhus glutinosa</i>	2.83	1.42	8.90
3	<i>Croton macrostachyus</i>	2.55	1.27	8.01
4	<i>Syzygium guineense</i>	2.45	1.22	7.69
5	<i>Ficus vasta</i>	2.06	1.03	6.46
	Total of the top 5 species	13.19	6.59	41.47
	Total of other 59 species	18.63	9.31	58.53
	Grand Total	31.81	15.91	100.00

4.5.3. Importance value Index (IVI)

Analysis of IVI revealed that the Endiras forest was highly dominated by 5 woody plant species (Table 9). These were *Carissa spinarum*, *Rhus glutinosa*, *Maytenus undata*, *Croton macrostachyus* and *Acacia lahai*. *Carissa spinarum* was the most important dominant species which contributed 21.19 IVI value followed by *Rhus glutinosa*, *Maytenus undata* and *Croton macrostachyus* with 18.22, 17.88 and 17.08 IVI value respectively. Therefore, greatest IVI reflects the extent of dominancy in a given species in relation to the other species in the structure of a forest stand. Woody species in Endiras Forest were grouped based on their IVI values for conservation priority (Appendices 4).

Table 9: IVI values of ten most dominant woody plant species in Endiras Forest.

No.	Species	RF	RD	RD	IVI	priority class
1	<i>Carissa spinarum</i>	5.36	13.60	2.22	21.19	1
2	<i>Rhus glutinosa</i>	4.99	4.34	8.90	18.22	1
3	<i>Maytenus undata</i>	4.86	9.95	3.07	17.88	1
4	<i>Croton macrostachyus</i>	4.99	4.09	8.01	17.08	1
5	<i>Acacia lahai</i>	2.87	2.86	10.38	16.11	1
6	<i>Syzygium guineense</i>	2.00	1.23	7.69	10.91	2
7	<i>Osyris quadripartita</i>	4.11	3.63	2.90	10.64	2
8	<i>Calpurnia aurea</i>	3.99	4.83	1.38	10.19	2
9	<i>Dodonea angustifolia</i>	3.62	3.52	2.82	9.95	3
10	<i>Bersama abyssinica</i>	3.87	3.01	2.92	9.79	3

The species in Endiras forest were grouped based on their IVI for conservation priority. The IVI classes and their number of species belong to each classes were described in (Table 10). Majority of the species were found in IVI classes of 4 and 5. IVI class 1 has the lowest number of species.

Table 10: IVI classes and their number of woody plant species in each class

IVI classes and values	Number of species	IVI total	Percentage
5 (<1)	16	9.96	3.32
4 (1.01-5)	27	68.04	22.68
3 (5.01-10)	13	47.09	15.70
2 (10.1-15)	3	76.42	25.47
1 (>15)	5	98.49	32.83
Total	64	300.00	100.00

4.5.4. DBH distribution

The distribution of plant species in different DBH classes was shown in (table 11). Matured woody plants of the study area were classified into seven DBH classes. Class A = 2.5-5 cm, B = 5.01-10, C = 10.01-15 cm, D = 15.01-20 cm, E = 20.01-30 cm, F = 30.01-40 cm and G = > 40 cm. The first class had the highest distribution of species density per hectare which was 64.41% followed by the second with 26.15%. As it is revealed in (Figure 8), inverted “J” shape population distribution was observed in diameter class of Endiras Forest.

Table 11: Diameter classes distribution

Diameter classes in cm (DBH)	Total stem number	Stem density ha-1	%
2.5-5	1646.00	2095.00	64.41
5.1-10	1598.00	850.50	26.15
10.1-15	1374.00	155.00	4.77
15.1-20	1115.00	66.00	2.03
20.1-30	598.00	45.00	1.38
30.1-40	97.00	23.50	0.72
>40	77.00	17.50	0.54
Total	6505.00	3252.50	100.00

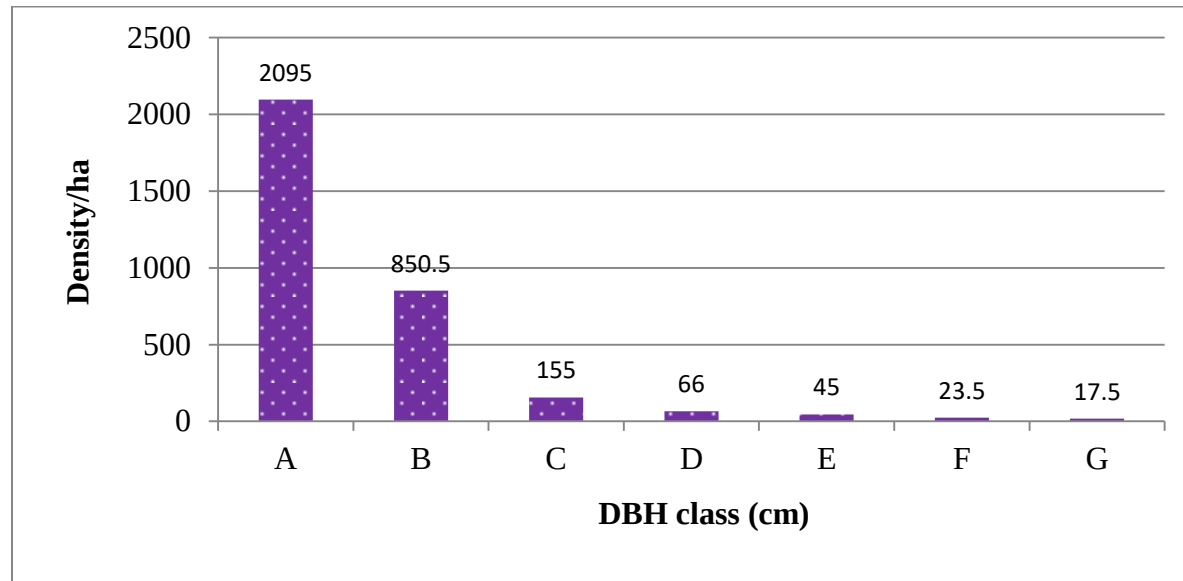


Figure 8: DBH class distribution of woody plants in Endiras Forest

4.5.5. Height

Individuals of woody species were classified into seven height classes (Table 12) and density/ha was calculated on this basis. The height class distribution of trees and shrubs in Endiras Forest showed that many individuals had the lowest height class (78.02%) in class A which was an inverted “J” distribution pattern (Figure 9). As height increases from one class to the other the density of individuals falls dramatically.

Table 12: Height class distribution

Height classes in (m)	Number of stem	Density ha ⁻¹	% Density
(A) 2.5-5	5075.00	2537.50	78.02
(B) 5.01-10	1262.00	631.00	19.40
(C) 10.01-15	121.00	60.50	1.86
(D) 15.01-20	18.00	9.00	0.28
(E) 20.01-25	15.00	7.50	0.23
(F) 25.01-30	9.00	4.50	0.14
G >30	5.00	2.50	0.08
Total	6505.00	3252.50	100.00

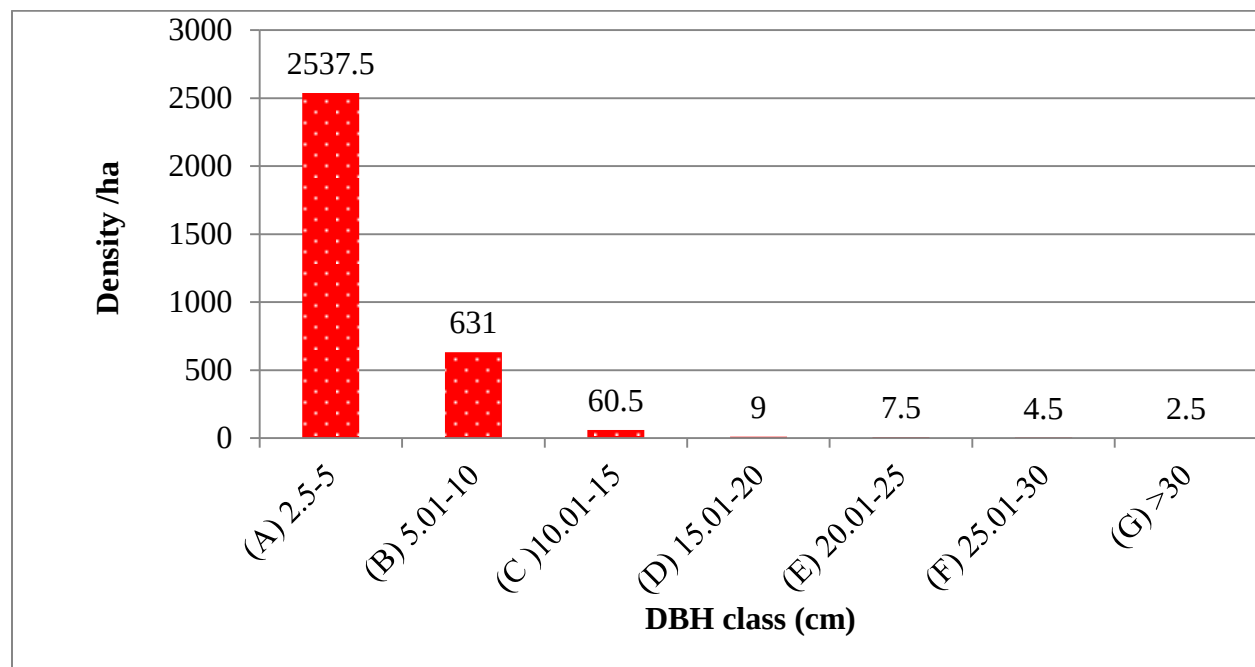


Figure 9: Height class distributions of woody plant species in Endiras Forest

4.5.6. Vertical Stratification

Each tree was classified into one of the tree storey according to its height. The tallest tree observed in Endiras forest was *Combretum collinum* with 31 m height. Trees in the lower, middle and upper height bands were those in the height range < 10 .33 m, 10 .33 – 20 m and > 20 m respectively (Table 13).

Table 13: Density, number of woody species and ratio of individuals to species by storey in Endiras forest

Storey	Height(m)	No. of stem/ha	Percent	No. of species	Percent	Ratio of individuals /ha to species
Lower	< 10.33	3134.5	96.37	60	73.17	52:1
Middle	10.33 – 20	103.5	3.18	18	21.95	5.75:1
Upper	> 20	14.5	0.45	4	4.88	3.63:1

Hence, the highest density of stem found in the lower storey (96.37%) and the lowest density was found in the upper storey (0.45%). Almost all woody species were concentrated in the lower storey 60 species followed by the middle 18 species. Therefore, the analysis of the vertical structure of the Endiras forest reveals that the majority of the floristic composition was found in the lower story of the vegetation.

4.5.7. Frequency

Based on the percentage frequency value, the woody plant species were classified into five frequency classes: A = 0-20, B = 20.01-40, C = 40.01-60, D = 60.01-80 and E = 80.01-100. The result showed that about 34 of the total woody species were distributed in the lower frequency class (Figure 10). The most frequently occurred species in the study area was *Carissa spinarum* (Table 14). It was found in 43 plots out of 50 plots.

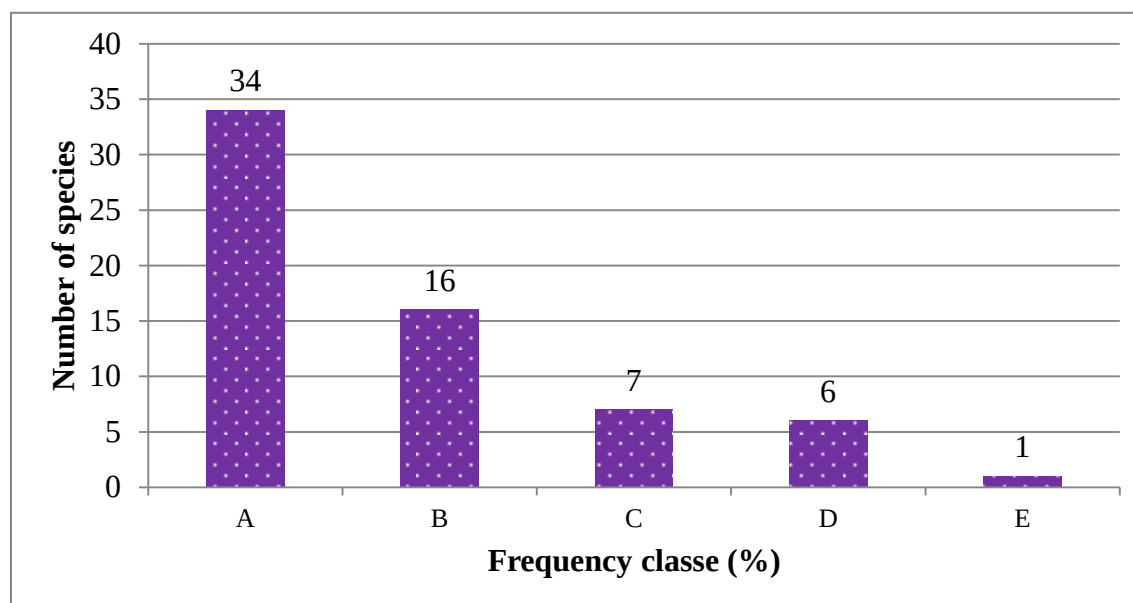


Figure 10: Frequency distribution. Key: A = 0-20, B = 20.01-40, C = 40.01-60, D = 60.01-80, E = 80.01-100

Table 14: Most frequent species in the study area

No.	Species	Frequency	Relative frequency (%)
1	<i>Carissa spinarum</i>	43	86
2	<i>Croton macrostachyus</i>	40	80
3	<i>Rhus glutinosa</i>	40	80
4	<i>Maytenus undata</i>	39	78
5	<i>Osyris quadripartita</i>	33	66
6	<i>Calpurnia aurea</i>	32	64
7	<i>Bersama abyssinica</i>	31	62
8	<i>premna schimperi</i>	30	60
9	<i>Dodonea angustifolia</i>	29	58
10	<i>Grewia ferruginea</i>	28	56

4.5.8. Population structure

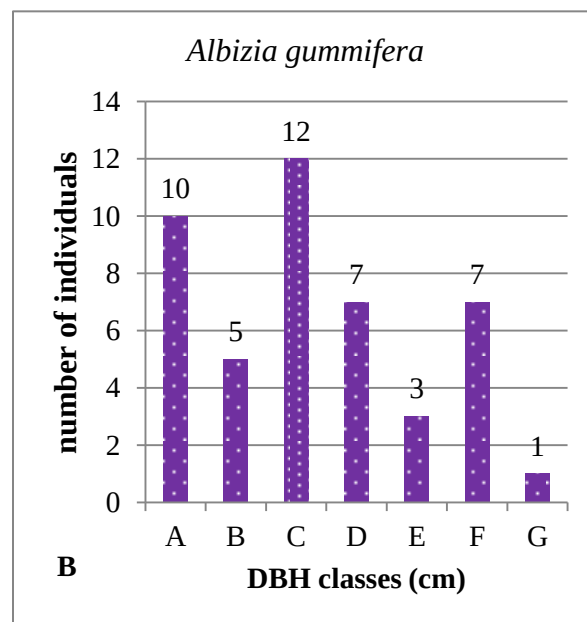
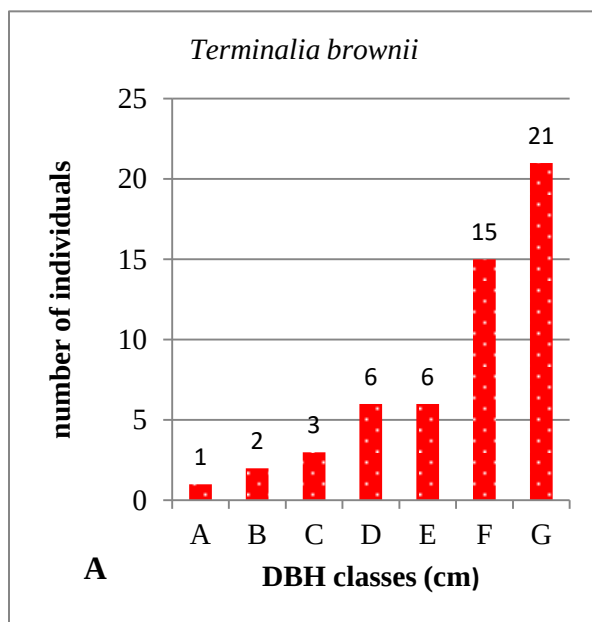
The patterns of diameter class distribution indicate the general trends of population dynamics and recruitment processes for a given species. Analysis of four tree species in the study site revealed four general patterns (Figure 11). The first pattern was 'J- shaped', which has a less number of species in the lower DBH classes and the number of individuals in the species showed

a gradual increase at the higher DBH classes. This pattern was exhibited by the species *Terminalia brownii* felled only in the first lower DBH class. Thus, this species was under recruitment (Figure 11A).

The second type of population pattern was ‘irregular shaped’; this type of frequency distribution shows that there were relatively larger numbers of individuals in the 1st and 3rd diameter classes and lower in other diameter classes. For instance it has been observed for *Albizia gummifera* distribution (Figure 11B).

The third type of population pattern was ‘bell shaped’ and was characterized by the species *Pittosporum viridiflorum*. It shows high number of individuals in the middle DBH classes but lower numbers of individuals in the lower and higher DBH class (Figure 11C).

The fourth type of population pattern was an ‘inverted J-shaped’ and was characterized by the species *Acacia lahai*. This pattern showed high number of individuals in the lower DBH classes and rapid reduction when moving from lower to higher DBH classes (Figure 11D).



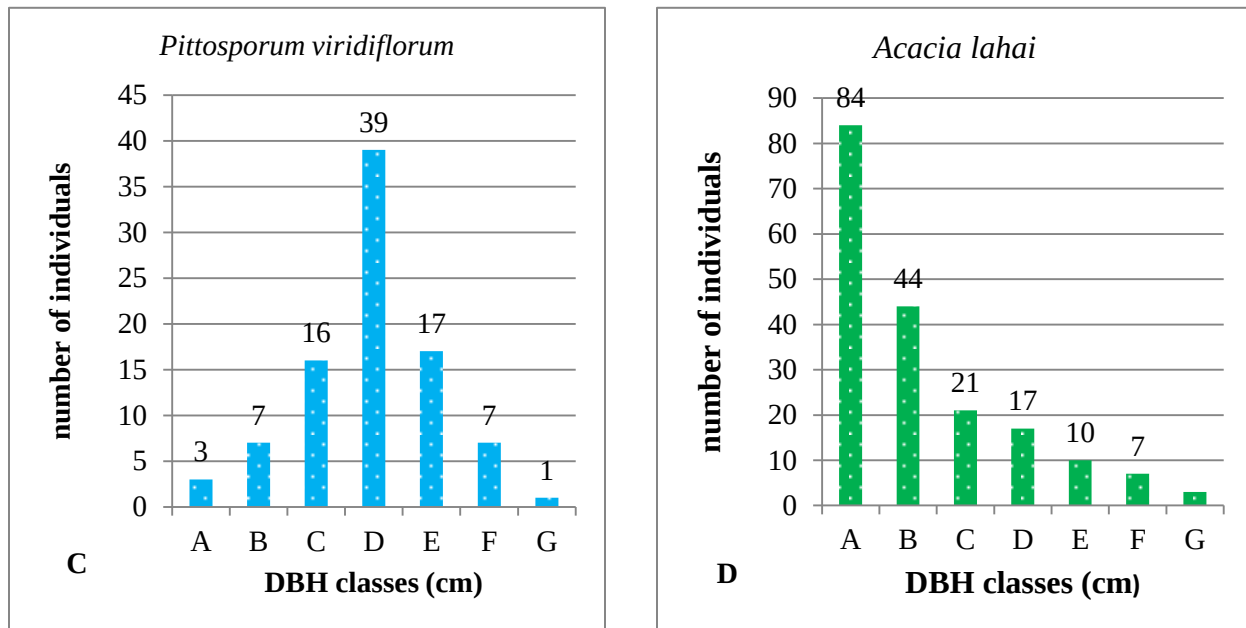


Figure 11: Different diameter class frequency distribution patterns for selected tree species in Endiras Forest (A-D). Patterns of population structure of representative woody species. DBH classes: A= 2.5 – 5 cm, B = 5.01 – 10 cm, C = 10.01 – 15 cm, D = 15.01 – 20 cm, E = 20.01 – 30 cm, F = 30.01- 40 cm, G = > 40 cm.

4.6. Regeneration Status

In the present study, the total density of seedlings, saplings and mature plants of the forest were 5398.4 ha⁻¹, 4782.4 ha⁻¹ and 3252.5 ha⁻¹ respectively (Appendix 5). The ratio analysis of woody species seedling to mature individuals in the forest gives that (1.66:1), seedling to sapling was (1.22:1) and sapling to mature (1.47:1). The result showed that there was more seedling than that of sapling and mature individuals implying the survival of seedling to reach sapling stage and the forest was now in a good regeneration.

Regeneration analysis for priority setting of woody plant species considered in the study area was classified into three groups based on the density of seedling (Table 15). Some of the species categorized under the first group were *Acacia lahai*, *Acacia persiciflora*, *Albizia malacophylla*, *Albizia schimperiana*, *Bridelia micrantha* (Table 15).

Table 15: Regeneration status of Endiras forest based on the density of seedlings

Group -1	Group -2	Group -3	
<i>Acacia lahai</i>	<i>Turraea holstii</i>	<i>Ficus vasta</i>	<i>Vernonia myriantha</i>
<i>Acacia persiciflora</i>	<i>Mimusops kummel</i>	<i>Maytenus obscura</i>	<i>Acanthus sennii</i>
<i>Albizia malacophylla</i>	<i>Allophylus abyssinicus</i>	<i>Ocimum lamiifolium</i>	<i>Grewia ferruginea</i>
<i>Albizia schimperiana</i>	<i>Croton macrostachyus</i>	<i>prema schimperi</i>	<i>Dodonea angustifolia</i>
<i>Albizia schimperiana</i>	<i>Rhamnus prinoides</i>	<i>Osyris quadripartita</i>	<i>Myrsine africana</i>
<i>Bridelia micrantha</i>		<i>Rhoicissus tridentate</i>	<i>Euclea racemosa</i>
<i>Buddleja polystachya</i>		<i>Rosa abyssinica</i>	<i>Maytenus undata</i>
<i>Celtis africana</i>		<i>Terminalia brownii</i>	<i>Syzygium guineense</i>
<i>Cordia africana</i>		<i>Acacia senegal</i>	<i>Clausena anisata</i>
<i>Dichrostachys cinerea</i>		<i>Dovyalis abyssinica</i>	<i>Calpurnia aurea</i>
<i>Embelia schimperi</i>		<i>senna singueana</i>	<i>Jasminum abyssinicum</i>
<i>Entada abyssinica</i>		<i>Bersama abyssinica</i>	<i>Capparis tomentosa</i>
<i>Erythrina abyssinica</i>		<i>Phoenix reclinata</i>	<i>Acanthus polystachius</i>
<i>Ficus palmata</i>		<i>Acokanthera schimperi</i>	<i>Pterolobium stellatum</i>
<i>Ficus sycomorus</i>		<i>Brucea antidysenterica</i>	
<i>Ficus thonningii</i>		<i>Pittosporum viridiflorum</i>	
<i>Flueggea virosa</i>		<i>Stereospermum kunthianum</i>	
<i>Hypericum quartinianum</i>		<i>Carissa spinarum</i>	
<i>Pittosporum abyssinicum</i>		<i>Albizia gummifera</i>	
<i>Sapium ellipticum</i>		<i>Millettia ferruginea</i>	
<i>Steganotaenia araliacea</i>		<i>Gardenia ternifolia</i>	
<i>Vernonia amygdalina</i>		<i>Combretum collinum</i>	
<i>Ximenia americana</i>		<i>Rhus glutinosa</i>	

The distribution of the natural regeneration potential of the woody species shows four different patterns such as J-shaped, U-shaped, Inverted J-shaped and Gauss types (Figure 12) The highest number of species (29) depicts J-shape patterns followed by 10 species which belongs to the Gauss types, while the least number of species (4) belong to inverted J-shape.

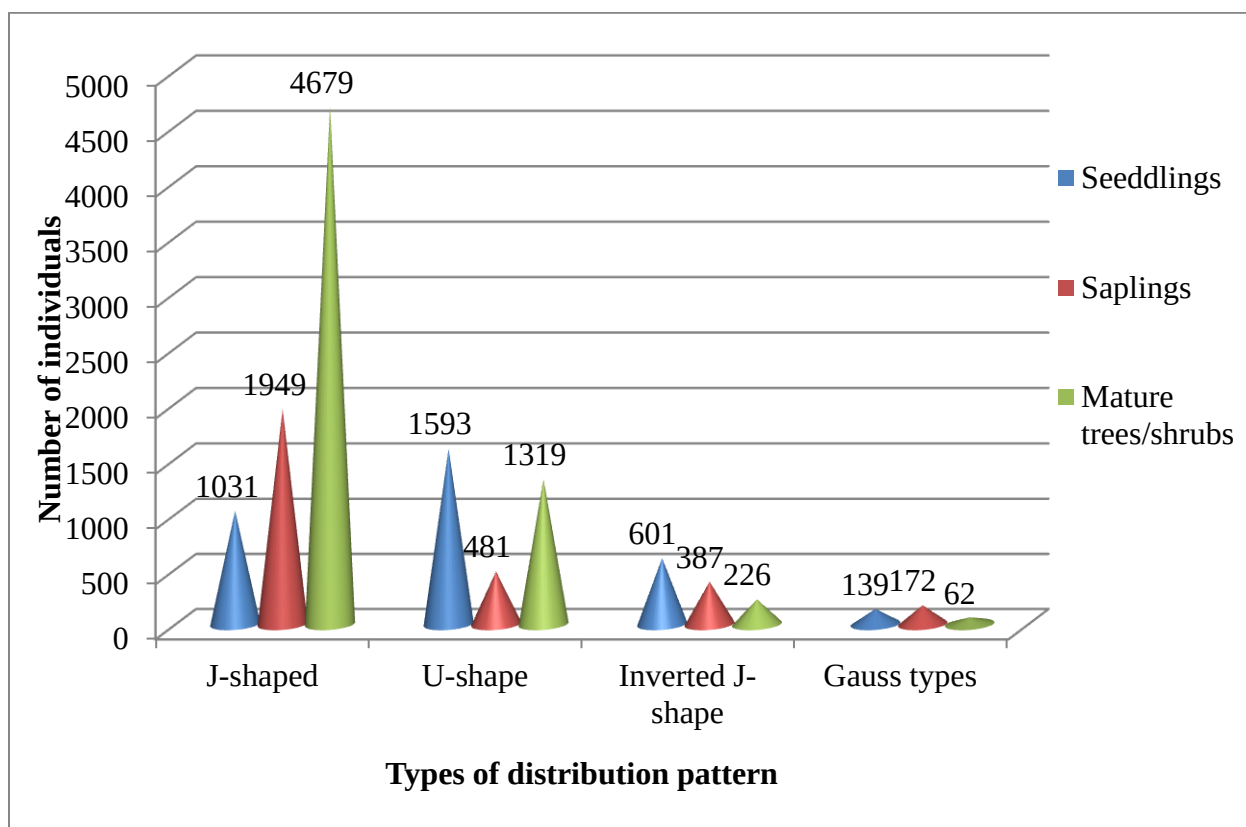


Figure 12: Seedlings, saplings and matured woody plant species distribution pattern

J-shape distribution pattern (poor regeneration potential): The distribution pattern characterized by high numbers of matured woody species and decreasing down to saplings and seedlings in logical order (Figure 12). A total of 29 species were represented by this distribution pattern such as *Acanthus polystachius*, *Maytenus undata*, *Dodonea angustifolia*, *Grewia ferruginea*, *Acanthus sennii*, *Vernonia myriantha*, *Rhus glutinosa*, *Gardenia ternifolia* and *Carissa spinarum* to mention only a few. Out of these, 1031 of individuals were seedlings, 1949 were saplings, and 4679 were matured trees/shrubs (Figure 12).

U-shape distribution pattern (fair regeneration potential): This type of pattern showed high numbers of seedlings and matured trees/shrubs compared to saplings (Figure 12). A total of 10 woody plant species belonging to this category were *Pterolobium stellatum*, *Allophylus abyssinicus*, *Calpurnia aurea*, *Capparis tomentosa*, *Croton macrostachyus*, *Euclea racemosa*, *Maesa lanceolata*, *Mimusops kummel*, *Syzygium guineense* and *Terminalia brownii*. Out of

these, 1593 of individuals were seedlings, 481 were saplings and 1319 were matured trees/shrubs.

Inverted J-shape distribution pattern (good regeneration potential): The distribution pattern characterized by high numbers of seedlings decreasing down saplings and matured woody species in logical order (Figure 12). A total of 7 species were represented by this distribution pattern such as *Acokanthera schimperi*, *Brucea antidysenterica*, *Clausena anisata*, *Combretum collinum*, *Jasminum abyssinicum*, *Myrsine africana* and *Phoenix reclinata*. Out of these, 601 of individual were seedlings, 387 were saplings and 226 were mature trees/shrubs.

Gauss distribution pattern (poor regeneration potential): This type of distribution has high number of individuals of saplings compared to seedlings and matured woody plant species (Figure 12). A total of 4 woody plant species were represented by this distribution such as *Albizia gummifera*, *Ficus vasta*, *Millettia ferruginea*, and *Stereospermum*. Out of these, 139 of individuals were seedlings, 172 were saplings and 62 were mature trees/shrubs.

Some of the mother plants such as *Bridelia micrantha*, *Buddleja polystachya*, *Celtis africana*, *Cordia africana*, *Dichrostachys cinerea*, *Embelia schimperi*, *Entada abyssinica*, *Ficus palmata*, *Ficus sycomorus*, *Flueggea virosa*, *Hypericum quartinianum*, *Sapium ellipticum*, *Steganotaenia araliacea* and *Vernonia amygdalina* have neither seedlings nor saplings and considered as **not regenerating** where as one species (*Rhamnus prinoides*) was found only in sapling stage but not in the seedling and matured tree/shrub in the sampled plot.

4.7. Impacts of Environmental Variables on Vegetation Distribution

According to the result using Analysis of Variance (ANOVA) conducted in conjunction with Canonical Correspondence Analysis (CCA), among 20 parameters considered for the this study, only eight of them were significant($p \leq 0.05$) such as altitude, aspect, browsing, pH, sand, Ca , OC, and available phosphorus, while others remained as non-significant (Table 16).

Table 16: ANOVA test to check the level of significance for environmental variables, Key: Df (Degree of freedom), Pr (Probability)

Variables	Df	Sum of square	Mean Square	F. Model	R ²	Pr (>F)
Altitude	1	0.4668	0.46684	2.2434	0.03618	0.01**
Slope	1	0.28645	0.28645	1.3765	0.0227	0.14
Aspect	1	0.3402	0.34024	1.635	0.2637	0.04*
grazing	1	0.2393	0.23934	1.1501	0.01855	0.35
cutting	1	0.2738	0.27383	1.3159	0.02122	0.23
Browsing	1	0.3654	0.36539	1.7559	0.02831	0.03*
pH	1	0.6696	0.66958	3.2176	0.05189	0.01**
EC	1	0.3146	0.31458	1.5117	0.02438	0.08
Sand	1	0.4006	0.4006	1.9251	0.03104	0.01**
Silt	1	0.2566	0.25658	1.233	0.01988	0.3
OC	1	0.4447	0.44468	0.1369	0.03446	0.01**
OM	1	0.2319	0.23187	1.1142	0.01797	0.34
TN	1	0.2552	0.25518	1.2263	0.01977	0.19
P	1	0.7925	0.79246	3.8082	0.06141	0.01**
Ca	1	0.4917	0.49167	2.3627	0.0381	0.01**
Residuals	34	7.0753	0.2081		0.54828	
Total	49	12.9046			1	
Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 at a permutation of 999						

Relationship of vegetation data and environmental variables as well as the environmental variables themselves (such as altitude, aspect, pH, sand, OC, P, and browsing) were calculated through fitting them on to CCA ordination scatterplots (Figure 14). The environmental factor with the longest arm was the most significant limiting factor. The result showed that altitude, pH, P, OC and sand were the most pressurizing factors affecting the vegetation followed by aspect, Ca and browsing (Figure 13). The different environmental variables were correlated to each other differently depending on the angle between the arrows. Altitude and sand for example,

were negatively correlated since the arrows were pointing in opposite direction while altitude and pH with an intermediate angle between the arrows were positively correlated. Altitude was positively correlated with axis one (x-axis) and axis two (y-axis) while aspect and sand were negatively correlated with the two axes. Ca was negatively correlated with axis one (x-axis) and positively correlated with axis two (y-axis). PH, P, OC, and browsing were positively correlated with axis one and negatively correlated with axis two with different gradient length.

Plot 7, 42, and 21 were outliers which were not significantly affected by the selected parameters. The vegetation of these plots may be influenced by other parameters which were not collected such as moisture content, soil depth, soil seed bank. Even if the effects of grazing, cutting trees and shrubs and collecting fuel wood were not noticed on the CCA graph they were also pressuring the vegetation of the study area (Figure 14).

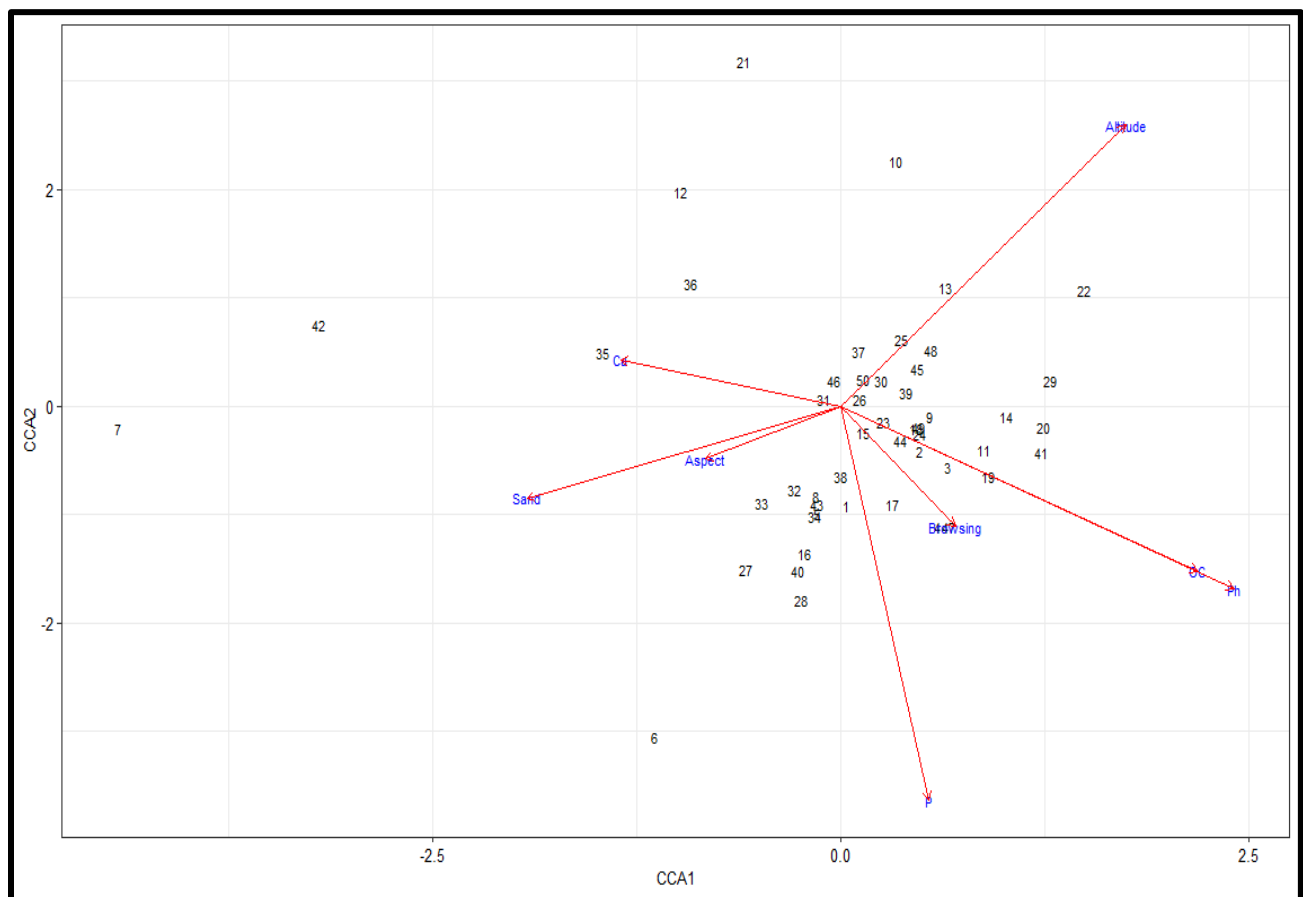


Figure 13: Impacts of environmental variables on vegetation distribution of Endiras forest



Figure 14: Effect of human pressure on the vegetation (a-c cutting effect) and grazing activities (d) in the study area (Photo taken by Worku Misganaw)

5. DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1. Discussion

5.1.1. Floristic composition

A total of 69 woody plant species, belonging to 57 genera and 36 families were recorded from the forest 65 inside the plots and 4 outside the plots (Appendix 1). The collected species were composed of 53.62% shrubs 42.03% trees, 4.35% lianas. Out of the total 69 species, the highest representation of species was from the family Fabaceae (15 species, 22.06%) in Endiras forest could be related to the fact that it is the second largest family in the flora of Ethiopia and Eritrea (Hedberg and Edwards, 1989). This could also be attributed to its efficient and successful dispersal strategies as well as better adaptation to a wide range of ecological conditions. Fabaceae was also found to be dominant in other Afromontane forests in Ethiopia like Belete (8 species, 10%) (Kitessa Hundera and Tsegaye Gadissa, 2008), Hugumburda (5 species, 6%) (Ermias Aynekulu *et al.*, 2011), Komto (12 species, 12%) (Fekadu Gurmessa *et al.*, 2012), and Jibat (14 species, 8%) (Tsfaye Burju *et al.*, 2013).

According to the red list of endemic tree and shrubs of Ethiopia and Eritrea from the total plant species three were endemic to Ethiopia (*Acanthus sennii*, *Millettia ferruginea* and *Rhus glutinosa*) of which one was near threatened (*Acanthus sennii*), one was least concern (*Millettia ferruginea*) and the other one vulnerable (*Rhus glutinosa*) in this study (Vivero *et al.*, 2005). Out of 120 threatened endemic plant species listed from Ethiopia 35 species were from dry Afromontane forests (Ensermu Kelbessa *et al.*, 1992). This shows that endemcity is high in the dry Afromontane Forest. This is due to the fact that endemism may arise by geographical and ecological isolations of species from the rest Kruckeberg and Rabinowitz (1985). But in Endiras forest less endemcity was recorded i.e. it accounts 8.6% of dry Afromontane Forest compared with Alemsaga which have seven endemic species. The reason was due to small size of the forest and the study only considers the woody plant species compared with other forests which have high endemism.

Among the forests in comparison, Endiras forest has the highest similarity with Quandisha and Jemjem forest in floristic composition. The number of woody species recorded in this study was higher than the findings of other similar studies in the afromontane such as Dodola, Menagesha

Wanzaye, Chilimo, Biteyu and Zengena forest. However, less number of species was recorded compared with Sheleko Medhanialem forest, Alemsaga forest and Gedo forest as shown in (Table 17). Because the study considered only woody plant species.

Table 17: Comparison of the floristic richness of different Afromontane forest with Endiras

Forest	Forest types	Richness	References
Dodola	Dry Afromontane	34	(Kitessa Hundera, 2003)
Menagesha	Dry Afromontane	48	(Tamrat Bekele, 1993)
Wanzaye	Dry Afromontane	49	(Ambachew Getnet , 2018)
Chilimo	Dry Afromontane	50	(Tamrat Bekele, 1993)
Biteyu	Dry Afromontane	47	(Tamrat Bekele, 1993)
Zengena	Dry Afromontane	50	(Desalegn Tadele <i>et al.</i> , 2014)
Jemjem	Dry Afromontane	65	(Hailu Sharew, 1982)
Quandisha	Dry Afromontane	66	(Abiyot Berhanu ,2015)
Sheleko Medhanialem	Dry Afromontane	82	(Sosina Hailu, 2016)
Alemsaga	Dry Afromontane	124	(Getinet Masresha <i>et al.</i> , 2015)
Gedo	Dry Afromontane	196	(Birhanu Kebede, 2010)
Endiras	Dry Afromontan	69	(Present study,2020)

5.1.2. Plant community types

The plant communities or vegetation cover of a given area has a definite structure and composition (Mueller-Dombois and Ellenberg, 1974). Five community types were identified in Endiras Forest. Community 1 was characterized by *Acacia lahai* - *Carissa spinarum*. Community 2, 3, 4 and 5 were dominated and characterized by *Buddleja polystachya* - *Croton macrostachyus*, *Syzygium guineense* - *Maytenus undata*, *Osyris quadripartita* - *Pittosporum viridiflorum*, and *Acacia Senegal* - *Rhus glutinosa* respectively.

The results from cluster analysis showed that there were differences among the five plant communities in species composition. The differences could be attributed to variations in environmental gradients that can limit the ecological distributions of plant species (Ermias Lulekal, 2014). As described in Tamrat Bekele (1993) and Zerihun Tadesse *et al.*, (2017), this

variation in species composition could also be related to the effects of environmental factors such as altitude, aspect, soil contents and moisture, human impacts and grazing intensity. Lower altitudinal ranges, aspects more exposed to sun light directions, soils with sufficient moisture contents and part of vegetation less exposed to disturbance accesses can support relatively more biodiversity than the reverse of each component.

The overall Shannon – Wiener diversity index ($H' = 3.40$) of Endiras forest indicated high diversity in the study area. This finding was found to be higher than that of other Ethiopian Afromontane forests like Chilimo ($H' = 2.72$) (Tadesse Woldemariam *et al.*, 2000), Tara Gedam ($H' = 2.98$) (Haileab Zegeye *et al.*, 2011) and lower than, Zegie ($H' = 3.72$), (Alemnew Alelign *et al.*, 2007), Wondo Genet ($H' = 3.60$) (Mamo Kebede *et al.*, 2013) forests. According to Kent and Coker (1992), the Shannon-Wiener diversity index normally varies between 1.5 and 3.5, and rarely exceeds 4.5. Thus, the H' value of Endiras forest resides within the normal range that indicates high plant species diversity of the study area, which may be related to the relatively high degree of topographic, climatic and edaphic factors differences in the area. The observed overall species evenness ($J = 0.82$) in Endiras forest was also higher than in Chilimo ($J = 0.68$) (Tadesse Woldemariam *et al.*, 2000) and Tara Gedam ($J = 0.65$) (Haileab Zegeye *et al.*, 2011), indicating a relatively much more equitable distribution of individuals among various species in the study area. The presence of different environmental gradients and high rate of forest disturbance due to human encroachment and livestock grazing, which are common in the study area are among the factors most responsible for variations in species diversity and evenness in a given forest.

5.1.3. Vegetation structure

5.1.3.1 Density of woody species

The ratio of density of individuals with $DBH\ 10 < DBH < 20\ cm$ to density $> 20\ cm$ was taken as a measure of the size class distribution (Grubb *et al.* 1963). In Endiras Forest, the most dominant woody plant species were represented in density class 8, and those which are represented with less number of species need conservation attention. The ratio of tree densities with $DBH\ 10 < DBH < 20\ cm$ to density $> 20\ cm$ in Endiras forest as shown in (Table 18); there was close similarity with Menagesha and Menna Anget Forest. The ratio X/Y indicate that Endiras Forest

had more tree in lower DBH classes than in the higher classes when compared to Gedo, Jibat, Menna Angetu, Abo Gedam and Menagesha Forest. The reasons behind these were geographical location, the nature of the forest, age of the forest, degree of conservation and exposure to disturbance.

Table 18: Comparison of tree densities with DBH between (10 and 20), and > 20cm of Endiras Forest with other 5 forests in Ethiopia

Forest	10 < DBH < 20 (x)	DBH >20(Y)	(X/Y)	Forest types	Source
Gedo	832.00	464	1.79	Dry Afromontane	(Birhanu Kebede,2010)
Menna Angetu	292.59	139.78	2.08	Dry Afromontane	(Ermias Lulekal <i>et al.</i> , 2008)
Jibat	565.00	287	2	Dry Afromontane	(Tamrat Bekele, 1993)
Abo Gedam	386	315	1.2	Dry Afromontane	(Getie Minassie,2016)
Menagesha	484.00	208	2.3	Dry Afromontane	(Tamrat Bekele, 1993)
Endiras	2489.00	772.00	3.22	Dry Afromontane	Present study(2020)

5.1.3.2. Basal area

Basal area, the area outline of a plant near the surface, is of particular interest for trees and can be used for tree volume estimations (Mueller-Dombois and Ellenberg 1974). There is direct relationship between DBH and basal area (Kent and Coker, 1992). The total basal area of the woody species that were found in the plots was 31.81/m² or 15.91/ha, indicates that the trees belonging to higher DBH classes were fewer but contribute much to the total basal area. The total basal area Endiras forest was 15.81/ha. Out of which 6.59 ha⁻¹ (41.47 %) was contributed by five species *Acacia lahai*, *Rhus glutinosa*, *Croton macrostachyus*, *Syzygium guineense*, *Ficus vasta* while the remaining 9.31 (58.53%) was contributed by the rest 59 species in (Table 8). Total basal area comparison between the current study of Endiras Forest and other 5 dry Afromontane forests in Ethiopia was shown in (Table 19).

Table 19: Basal area (BA) Comparison of Endiras Forest with other 6 Afromontane forests

Forest	Basal area ha ⁻¹	Forest types	Source
Yangudi- Rasa	3.12	Dry Afromontane	Semere Beyene (2010)
Beschillo and Abay	12.6	Dry Afromontane	Getaneh Belachew (2006)
Wanzaye	23.3	Dry Afromontane	Ambachew Getnet (2018)
Sheleko Medhanialem	23.56	Dry Afromontane	Sosina Hailu (2016)
Menagesha	36.1	Dry Afromontane	Tamrat Bekele (1993)
Alemsaga	75.37	Dry Afromontane	Getinet Masresha <i>et al.</i> (2015)
Endiras	15.91	Dry Afromontan	Present study (2016)

Table 19 showed that Endiras Forest had a basal area greater than that of Yangudi- Rasa, and Beschillo and Abay forests but lower than that of Alemsaga, Menagesha, Sheleko Medhanialem and Wanzaye forests. The trees belonging to higher DBH classes in Endiras Forest were only few but contributed significantly to the total basal area as shown in (Figure 8). Few large plants contributed a disproportionally large share of the total basal area in Endiras. For example, *Rhus glutinosa*, *Acacia lahai*, *Carissa spinarum*, *Carissa spinarum*, *Maytenus undata*, *Pittosporum viridiflorum* contributed about 53.92 % of the total basal area (Table 8).

5.1.3.3. Importance Value Index (IVI)

According to Simon Shibru and Girma Balcha (2004) species with the greatest importance value index are the most dominant of the particular vegetation. It is also used for setting species priority for management and conservation practices and helps to identify their sociological status in a certain plant species as dominant or rare species (Kent and Coker, 1992). Those species with lower IVI values need high conservation efforts while those with higher IVI values need monitoring management. Plant species in priority class 5 such as *Turraea holstii* (0.16), *Allophylus abyssinicus* (0.21), *Cordia africana* (0.26) and *Mimusops kummel* (0.35) were few of the species which had the lowest IVI values (Appendix 4). This should get the uppermost conservation priority since they were at risk of local extinction. Whereas *Carissa spinarum* (21.19), *Rhus glutinosa* (18.22), *Maytenus undata* (17.88), *Croton macrostachyus* (17.08), *Acacia lahai* (16.11), *Syzygium guineense* (10.91), *Osyris quadripartita* (10.64), *Calpurnia aurea* (10.19) were species with high important value index need monitoring management

(Appendix 4). High basal area values of these species were the major factors explaining the high IVI values.

5.1.3.4. DBH distribution and height class distribution

The patterns of DBH class distributions indicate the general trends of population dynamics and recruitment processes of species in a given forest. The results on DBH class distribution of trees and shrubs across the seven DBH classes in Endiras forest indicated an inverted J-shape distribution (Figure 8). This was a general pattern of normal population structure where the majority of the species had the highest number of individuals at lower DBH classes with a gradual decrease towards the higher classes. Such inverted J-shape distributions across DBH classes are indicative of an overall healthy regenerating forest (Silvertown and Doust, 1993). Similar pattern of population structure was reported in previous studies from different Afromontane forests of Ethiopia (e.g. Feyera Senbeta and Demel Teketay, 2003; Kitessa Hundera *et al.*, 2007; Haile Yineger *et al.*, 2008; Haileab Zegeye *et al.*, 2011; Fekadu Gurmesssa *et al.*, 2012; Tesfaye Burju *et al.*, 2013; Ermis Lulekal, 2014).

Distribution of individuals in different height classes also reveals a similar trend in Bore-Anferara-Wadera forest. The percent distribution of trees and shrubs decreased with increasing height classes showing an inverted J-shape pattern of distribution, indicating selective cutting of individuals in that particular height class (Figure 9) and the dominance of small-sized individuals in the forest, which was a characteristic of the high rate of regeneration. Height can be used as an indicator of the age of the forest.

5.1.3.5. Vertical stratification

The result obtained from analysis of the vertical structure of Endiras forest indicates that the highest proportion of species was concentrated in the lower storey followed by the middle and upper storey. Hence, the result confirms that there was the dominance of small-sized individuals in the forest indicating that it was in a stage of secondary development. A similar result was reported by Ensermu Kelbessa and Teshome Soromessa (2008) and Fekadu Gurmesssa *et al.* (2012) in Bonga and Komto forests, respectively. The species that is common to all tree height profiles were described as species with regular distribution in all layers (Lamprecht, 1989). The

highest tree distribution in the lower storey and lowest height class implies that the forest has been heavily influenced by the local anthropogenic activities through selective cutting for fuel wood, construction and illegal wood harvest for timber production as it was now in different stages of secondary development.

5.1.3.6. Frequency

Frequency is defined as the probability or chance of finding a species in a given sample area or quadrant (Kent and Cooker, 1992). The frequency gives an approximate indication of the homogeneity and heterogeneity of species. Lamprecht (1989) pointed out that high value in higher frequency and low value in lower frequency classes indicate constant or similar species composition. Conversely, high percentage of the number of species in the lower frequency classes and low percentage of number of species in the higher frequency classes point out a high degree of floristic heterogeneity (Simon Shibru and Girma Balcha, 2004). Frequency gives a certain indication of uniformity of distribution rather than density. Of course the species with few individual can never show high frequency values, even if they are uniformly distributed. Therefore, frequency confounds the two parameters density and dispersion (Mueller-Dombois and Ellenberg, 1974). In Endiras forest *Carissa spinarum*, *Rhus glutinosa*, *Croton macrostachyus* and *Maytenus undata* were the most frequently occurred species. This was due to their high density (Table 14).

5.1.3.7. Population structures of selected trees

Population structures of trees have significant implications to their management, sustainable use and conservation strategies (Simon Shibru and Girma Balcha, 2004). Population pattern is helpful to understand the population density, regeneration and recruitment status of particular vegetation (Demel Teketay, 2005). Based on this concept, four population patterns of tree species were observed from the analyzed data in this study.

The first population pattern (“J” shaped pattern) represented by *Terminalia brownii* as shown in (Figure 11A), indicates that majority individuals of the species were distributed in the higher DBH classes (class 4 - 8) which gradually decreased and almost absent from the lower DBH classes. Similarly such pattern shows poor reproduction patterns in the finding of *Feyera Senbeta*

(2006) and hampered regeneration due to the fact that either most trees are not producing seeds due to age or there are losses due to predators after reproduction (Feyera Senbeta, 2006).

The second pattern was formed by species having irregular distribution over diameter classes. Some DBH classes had small number of individuals while other DBH classes had large number of individuals (Tesfaye Burju *et al.*, 2013). This irregular pattern distribution was due to selective cutting by the local people for construction and firewood. Overgrazing which affects the seedlings under the mother tree could be another reason for such irregularities. Examples of this pattern were represented by *Albizia gummifera* (Figure 11B).

The third type of population pattern was bell shaped and was characterized by the species *Pittosporum viridiflorum* (Figure 11C). It showed a fairly high number of individuals of the species in the middle DBH classes but lower numbers of individuals of the species in the lower and higher DBH classes. Species characterized by bell shaped structure has poor recruitment potential which might be due to intense competition between the other species found in its surroundings (Markos Kuma and Simon Shibru, 2015).

The fourth pattern was an inverted J-shaped distribution exhibited by species with high number of individuals in the first and second DBH classes and with gradual decreased towards higher DBH classes (Figure 11D), which suggested good reproduction and healthy regeneration potential of the species in the forest (Feyera Senbeta, 2006). This group was represented by *Acacia lahai* which had few numbers of species in upper DBH classes.

5.1. 4. Regeneration status of Endiras Forest

The presence of seedling recruitment is a building block in the population dynamics of many species of trees (Uriarte *et al.*, 2015). So that it is one of the important point in determining local abundance and diversity of mature tree. With this regard, out of the total analyzed tree and shrub 14 species were with no seedling and sapling and they were put in the first priority class as they were represented by no individual. If no urgent action is taken, they will be locally extinct those were *Bridelia micrantha*, *Buddleja polystachya*, *Celtis africana*, *Cordia africana*, *Dichrostachys cinerea*, *Embelia schimperi*, *Entada abyssinica*, *Ficus palmata*, *Ficus sycomorus*, *Flueggea*

virosa, *Hypericum quartinianum*, *Sapium ellipticum*, *Steganotaenia araliacea* and *Vernonia amygdalina*.

Regeneration status of the forest was analyzed by comparing saplings and seedlings with the matured trees. Good regeneration, if seedlings > saplings > adults; Fair regeneration, if seedlings > or $\leq$ saplings $\leq$ adults; Poor regeneration, if the species survives only in sapling stage, but no seedlings (saplings may be <, > or = adults); and if a species is present only in an adult form it is considered as not regenerating (Tiwari *et al.* 2010). The ratio analysis of woody species seedling to mature individuals in the forest gives that (1.66:1), seedling to sapling was (1.22:1) and sapling to mature (1.47:1). The result showed that there was more seedling than that of sapling and mature individuals implying the survival of seedling to reach sapling stage and the forest was now in a good regeneration. However there were also species with no seedling and sapling that may be caused by due to the physical condition of their microhabitat and human impacts and need urgent measurement to be taken as they were in poor regeneration.

5.1. 5. Environmental variables

The analysis of vegetation data using cluster analysis and ordination techniques can provide more detailed and inclusive information on the patterns of vegetation and the response of plant species to the principal environmental factors (Ter Braak, 1995). Variables that could significantly explain the spatial distribution of species or plant community distributions was identified by AKaike Information Criterion (AIC) shown in (Appendix 6) and ANOVA (Table 16). From the comparison of level of significance, out of twenty variables eight were better to explain the floristic diversity (Altitude, Aspect, Browsing, pH, and sand, OC, P and Ca). All exchangeable bases such as Mg, K and Na were not significant except Ca. In the current study, analysis of vegetation using ordination techniques indicated that the pattern of plant species distribution was mainly influenced by environmental factors such as altitude, aspect, disturbance and soil factors. Among these factors, altitude is an important topographical variable since it affects atmospheric pressure, moisture and temperature, which govern the growth and the distribution of plant. Previous studies by Bonnefille *et al.*, (1993), Kumelachew Yeshitela and Tamrat Bekele (2002) noted that the vegetation types in Southwest Ethiopia are mainly delimited by microclimatic conditions associated with altitude. This was also supported with similar

studies in Afroalpine vegetation by Hedberg (1964) altitudinal gradient were found to be the most complex environmental gradients encompassing many different interacting factors.

The significant positive correlation was observed among altitude, OC, phosphorus and pH but negative with sand and aspect. The positive correlation between altitude and pH were explained by the fact that, at high altitude and rainfall normally result in high erosion which creates the silt and clay content of the soil to be washed down to the lower altitudes. The significant positive correlation was observed between altitude and aspect, because aspect refers the orientation of plot which affects the precipitation and temperature level (Barbour *et al.*, 1987). Similar result was found in Bale Mountains investigated by Uhlig (1988) and Daniel Gamachu (1977) of which the southwest aspect received relatively high moisture from Atlantic Ocean than the northeast aspect influenced by the offshore trade winds. But in the recent study, the impact of aspect was not significant. PH of the soil was positively correlated with altitude indicating that the soil PH increases with increasing altitude. The pH of the soil can affect the chemical reaction between plant roots and nutrients, available in the soil for plant use and for microbial activity. Donahue *et al.*, (1983) showed that nutrient solubility; organic matter decomposition and some physical properties of soil were affected by soil pH.

The overall assessment made in the vegetation revealed that anthropogenic impacts have been affecting its natural regeneration. The act of cutting made especially on small to medium sized trees and shrubs and destruction of the vegetation as a result of the demand for fuel wood and to build homes by the local people as shown in (Figure 10) that indicates the vegetation has been under serious threats. Grazing was another problem identified in the study area where cattle encroached heavily into the vegetation.

5.2. Conclusion

Endiras Forest is one of the forests in Ethiopia which has relatively high woody species diversity that comprises a total of 69 woody plant species (trees, shrubs and woody climbers/liana) in 57 genera and 36 families collected from the Forest. Fabaceae had the highest number of species followed by Euphorbiaceae and Moraceae. Out of the total plant species recorded from the forest, 53.62% were shrubs while 42.03% and 4.35% were trees and woody climbers/lianas

respectively. Of the total species, identified from the study area, three were found to be endemic to the Flora of Ethiopia as already included in the IUCN red data list category.

The vegetation was grouped into five community types each of which had varying degrees of species richness, diversity and evenness. The results of Shannon- Wiener diversity index showed that, community type 1 (58 species) had the highest species richness, evenness and diversity. This community achieved a species evenness index of 0.92. Community type 3 was the second followed by community type 2 and 5. Community type 4 showed the lowest species richness, evenness and diversity. The variation among communities could be due to different factors (altitude, aspect, browsing, pH, sand, OC, P and Ca and anthropogenic). The overall Shannon–Wiener diversity (H') and evenness (J) woody species in Endiras Forest were 3.40 and 0.82, respectively.

The general trend of population structure showed an inverted J-shape for DBH classes. The majority of the species had a large number in smaller-diameter size classes with decreasing frequency as the size class increased. If a particular tree species displays such a size distribution, then continuous recruitment can generally be inferred, suggesting that the population is viable as sufficient regeneration is taking place for the population to be maintained. Even though the overall DBH distribution revealed inverse-J shape, different population dynamics for different species were revealed. Accordingly, four population patterns have been observed; inverted J-shaped, irregular shaped, J shaped and bell shaped. The analysis of frequency class in Endiras forest showed that Endiras Forest was floristically heterogeneous.

Analysis of regeneration of some selected woody species revealed that *Bridelia micrantha*, *Buddleja polystachya*, *Celtis africana*, *Cordia africana*, *Dichrostachys cinerea*, *Embelia schimperi*, *Entada abyssinica*, *Ficus palmata*, *Ficus sycomorus*, *Flueggea virosa*, *Hypericum quartinianum*, *Sapium ellipticum*, *Steganotaenia araliacea* and *Vernonia amygdalina* has no seedlings and saplings. These species need urgent conservation measures that will bring a healthy regeneration and consequently their sustainable use.

Altitude, aspect, browsing, pH, sand, OC, P and Ca were found to be among the main environmental variables structuring the plant species composition as well as plant community

types of the study area, among these sand, pH and silt were the most influential environmental variables.

5.3. Recommendations

Plant species are the potential stock for future genetic resources, and would have great implications for the environment, biological diversity and socio-economic importance. The inclusion of local communities in the forest conservation activities and management is the only realistic option to reduce the forest loss and its various resources as complex and valuable natural resource system. The result of this study can contribute towards understanding of the floristic composition, species diversity, structure, regeneration status and the floristic composition in relation with environmental factors of Endiras forest. Based on the results of the study, the following recommendations were drawn:

- Participatory forest management programs should be introduced and implemented so that all local communities feel responsibility for the management and conservation of the forest.
- Species with low IVI values such as *Turraea holstii*, *Allophylus abyssinicus*, *Cordia africana*, *Mimusops kummel*, *Ficus palmata*, *Celtis africana*, *Brucea antidysenterica*, *Vernonia amygdalina*, *Bridelia micrantha* and *Ocimum lamiifolium* should be given appropriate attention and conserved in-situ through the collaboration of local communities and the district agriculture and rural development office, NGOs and other stakeholders.
- Involvement of all community elders and Agricultural office as the chair person in the formation of local rules and regulation for sustainable use of the forest.
- Further investigation on the patterns of ecosystem functioning, the soil seed banks, seeds viability test, establishment of seedlings and studies on the role of gap dynamics and population distribution for selected species should be carried out.
- Raising public awareness of the local community and introduction of participatory management programs should be encouraged and implemented.
- Ethnobotanical studies and exploration of indigenous knowledge on the diverse uses of the plants should be undertaken to promote the sustainable use of the area.
- Modern beekeeping and marketing should be initiated in the area to improve income of local community.

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APPENDICES

Appendix 1: List of plant species collected from Endiras Forest

Key: T = Tree; SH = Shrub; L= Liana, (* = Endemic woody plant species, ** = woody plant species found outside the plot as matured plant, *** = woody plant species found inside the plot only as sapling stage)

No	Local name (Amharic)	Scientific name	Family	Life form	Collection code
1	Yehabesha girar	<i>Acacia abyssinica</i> Hochst. **	Fabaceae	T	WM68
2	Tinbilka girar	<i>Acacia lahai</i> Steud. and Hochst.ex Benth.	Fabaceae	T	WM02
3	Nech girar	<i>Acacia persiciflora</i> Pax	Fabaceae	T	WM49
4	Kontir girar	<i>Acacia senegal</i> (L.) Willd.	Fabaceae	T	WM04
5	Wende kusheshile	<i>Acanthus sennii</i> Chiov.*	Acanthaceae	SH	WM39
6	Sete kusheshile	<i>Acanthus polystachius</i> Delile	Acanthaceae	SH	WM15
7	Merenez	<i>Acokanthera schimperi</i> (A.DC.) Schweinf.	Apocynaceae	SH	WM58
8	Sesa/qachena	<i>Albizia gummifera</i> (J. F. Gmel.) C. A. Sm. *	Fabaceae	T	WM33
9	Sendil	<i>Albizia malacophylla</i> (A. Rich) Walp.	Fabaceae	SH	WM08
10	Dimeto	<i>Albizia schimperiana</i> Oliv.	Fabaceae	T	WM32
11	Embis	<i>Allophylus abyssinicus</i> (Hochst.) Radlk.	Sapindaceae	T	WM50
12	Azamer	<i>Bersama abyssinica</i> Fresen.	Melanthaceae	SH	WM64
13	Yeneber tifer	<i>Bridelia micrantha</i> Hochst. Baill.	Euphorbiaceae	T	WM45
14	waginose	<i>Brucea antidysenterica</i> J. F. Mill.	Simaroubaceae	SH	WM28
15	Nech anfar	<i>Buddleja polystachya</i> Fresen.	Loganiaceae	SH	WM29
16	Degita	<i>Calpurnia aurea</i> (Ait.) Benth.	Fabaceae	SH	WM57
17	Gimero	<i>Capparis tomentosa</i> Lam.	Capparidaceae	SH	WM65
18	Agam	<i>Carissa spinarum</i> L.	Apocynaceae	SH	WM01
19	Qawot	<i>Celtis africana</i> Burm.	Ulmaceae	T	WM34
20	Limich	<i>Clausena anisata</i> (Willd.) Benth.	Rutaceae	SH	WM47
21	Miserech	<i>Clerodendrum myricoides</i> (Hochst.) Vatke**	Lamiaceae	SH	WM27
22	Yekola abalo	<i>Combretum collinum</i> Fresen. subsp. <i>collinm</i>	Combretaceae	T	WM66
23	Wanza	<i>Cordia africana</i> Lam.	Boraginaceae	T	WM55
24	Bisana	<i>Croton macrostachyus</i> Del.	Euphorbiaceae	T	WM11
25	Gorgoro	<i>Dichrostachys cinerea</i> (L.)Wight and Arn.	Fabaceae	SH	WM43
26	Kitikita	<i>Dodonea angustifolia</i> L.F.	Sapindaceae	SH	WM06
27	Koshim	<i>Dovyalis abyssinica</i> (A.Rich) Warb.	Flacourtiaceae	SH	WM46
28	Enkoko	<i>Embelia schimperi</i> Vatke	Myrsinaceae	L	WM22
29	Mogne sesa/emblita	<i>Entada abyssinica</i> Steud.ex A. Rich.	Fabaceae	T	WM61
30	Kuwara	<i>Erythrina abyssinica</i> Lam ex DC.	Fabaceae	T	WM53
31	Dedehe	<i>Euclea racemosa</i> Murr. Subsp. <i>schimperi</i> (A.DC.) White	Ebenaceae	SH	WM10

32	Debase/beles	<i>Ficus palmata</i> Forssk.	Moraceae	T	WM59
33	Bamba	<i>Ficus sycomorus</i> L.	Moraceae	T	WM12
34	Chibiha	<i>Ficus thonningii</i> Blume	Moraceae	T	WM09
35	Warika	<i>Ficus vasta</i> Forssk	Moraceae	T	WM19
36	Wenahe	<i>Flueggea virosa</i> (Willd.)Voigt.	Euphorbiaceae	SH	WM63
37	Gambelo	<i>Gardenia ternifolia</i> Schumach. and Thonn. subsp. <i>jovis-tonantis</i> (Welw.) Verdc	Rubiaceae	T	WM13
38	Lenikuwata	<i>Grewia ferruginea</i> Hochst. Ex A. Rich.	Tiliaceae	SH	WM41
39	Yekola amiga	<i>Hypericum quartinianum</i> A.Rich.	Guttiferae	SH	WM52
40	Tenbelel	<i>Jasminum abyssinicum</i> Hochst.ex DC.	Oleaceae	L	WM18
41	Sete atat/atat	<i>Maytenus undata</i> (Thunb.) Blakelock	Celastraceae	SH	WM16
42	Wonide atat	<i>Maytenus obscura</i> (A. Rich.) Cuf.	Celastraceae	SH	WM56
43	Biribira	<i>Millettia ferruginea</i> (Hochst.) Bak. subsp. <i>Ferruginea</i>	Fabaceae	T	WM48
44	Eshe	<i>Mimusops kummel</i> A. DC.	Sapotaceae	T	WM57
45	Kelabo/kuraba	<i>Maesa lanceolata</i> Forssk.	Myrsinaceae	SH	WM26
46	Kechem	<i>Myrsine africana</i> L.	Myrsinaceae	SH	WM17
47	Damakese	<i>Ocimum lamiifolium</i> Hochst ex Benth.	Lamiaceae	SH	WM05
48	Keret	<i>Osyris quadripartita</i> Decn.	Santalaceae	SH	WM21
49	Selen	<i>Phoenix reclinata</i> Jacq.	Arecaceae	T	WM38
50	Yekola wanza	<i>Piliostigma thonningii</i> (Schumach.) Milne Redh- Redh. **	Fabaceae	T	WM67
51	Ankuwalit	<i>Pittosporum viridiflorum</i> Sims.	Pittosporaceae	T	WM07
52	Ankuwalit-2	<i>Pittosporum abyssinicum</i> Del.	Pittosporaceae	SH	WM31
53	Checho	<i>Premna schimperi</i> Engl.	Lamiaceae	SH	WM40
54	Kentefa	<i>Pterolobium stellatum</i> (Forssk.) Brenan	Fabaceae	SH	WM20
55	Gesho	<i>Rhamnus prinoides</i> L'Herit. ***	Rhamnaceae	SH	WM35
56	Wedel asifes	<i>Rhoicissus tridentate</i> (L. f.) wild and Drummond	Vitaceae	L	WM36
57	Kimo	<i>Rhus glutinosa</i> A.Rich. Subsp. <i>Glutinosa</i> *	Anacardiaceae	SH	WM44
58	Kega	<i>Rosa abyssinica</i> Lindley	Rosaceae	SH	WM62
59	Arbog	<i>Sapium ellipticum</i> (Krauss) Pax	Euphorbiaceae	T	WM54
60	Dingay seber	<i>Scolopia theifolia</i> Gilg. **	Flacourtiaceae	SH	WM69
61	Bshibsha	<i>Senna singueana</i> (Del.) Lock	Fabaceae	SH	WM30
62	Yegib dula	<i>Steganotaenia araliacea</i> Hochst.ex A. Rich.	Apiaceae	T	WM42
63	Zana	<i>Stereospermum kunthianum</i> Cham.	Bignoniaceae	T	WM23
64	Dokima	<i>Syzygium guineense</i> (Willd.) DC.	Myrtaceae	T	WM14
65	Wenbela	<i>Terminalia brownii</i> Fresen.	Combretaceae	T	WM24
66	Yetota merek	<i>Turraea holstii</i> Gurke	Meliaceae	SH	WM60
67	Kotikoto	<i>Vernonia myriantha</i> Hook.f.	Asteraceae	SH	WM25
68	Girawa	<i>Vernonia amygdalina</i> Del.	Asteraceae	SH	WM37
69	Enkoy	<i>Ximenia americana</i> L.	Olaceaceae	SH	WM03

Appendix 2: List of families with number of genera and species

Family	No of genus/ genera	No. of species
Fabaceae	10	15
Euphorbiaceae	4	4
Moraceae	1	4
Lamiaceae	3	3
Myrsinaceae	3	3
Acanthaceae	1	2
Apocynaceae	2	2
Asteraceae	1	2
Celastraceae	1	2
Combretaceae	2	2
Oleaceae	2	2
Pittosporaceae	1	2
Sapindaceae	2	2
Flacourtiaceae	2	2
Anacardiaceae	1	1
Apiaceae	1	1
Arecaceae	1	1
Bignoniaceae	1	1
Boraginaceae	1	1
Capparidaceae	1	1
Ebenaceae	1	1
Guttiferae	1	1
Loganiaceae	1	1
Meliaceae	1	1
Melianthacea	1	1
Myrtaceae	1	1
Rhamnaceae	1	1
Rosaceae	1	1
Rubiaceae	1	1
Rutaceae	1	1
Santalaceae	1	1
Sapotaceae	1	1
Simaroubaceae	1	1
Tiliaceae	1	1
Ulmaceae	1	1
Vitaceae	1	1
Total	57	69

Appendix 3: Synoptic cover-abundance values for species having a value of > 0.5 at least in one community type.

No.	Species	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
1	<i>Acacia lahai</i>	4.08	1.14	1	0.89	0.31
2	<i>Acacia persiciflora</i>	0.67	0.71	0	0	0
3	<i>Acacia senegal</i>	0	1.57	1	1	3.31
4	<i>Acanthus sennii</i>	0.58	1.57	0.22	0.11	0.23
5	<i>Acanthus polystachius</i>	1.17	1.29	0.22	0.78	2.08
6	<i>Acokanthera schimperi</i>	0	0	0.67	0.67	0
7	<i>Albizia malacophylla</i>	0.67	0	0.33	0.44	0
8	<i>Albizia gummifera</i>	0.42	0.71	0.89	1.11	0.85
9	<i>Albizia schimperiana</i>	1	0	0.33	0.56	1.46
10	<i>Allophylus abyssinicus</i>	0	0	0	0	0.23
11	<i>Bersama abyssinica</i>	1.25	2.14	1.22	1.22	2.23
12	<i>Bridelia micrantha</i>	0	0	0	0	0.62
13	<i>Brucea antidysenterica</i>	0	0.43	0.22	0	0
14	<i>Buddleja polystachya</i>	0.25	3.29	0.11	0	0.23
15	<i>Calpurnia aurea</i>	2.25	2.71	0.89	0.67	1.46
16	<i>Capparis tomentosa</i>	1.42	1.57	0	0	0.77
17	<i>Carissa spinarum</i>	3.08	1	2.67	3.01	2.5
18	<i>Celtis africana</i>	0.25	0	0	0	0.23
19	<i>Clausena anisata</i>	0.58	0.14	0	0	0.46
20	<i>Combretum collinum</i>	0.92	1	0.11	0	0.54
21	<i>Cordia africana</i>	0	0	0	0	0.23
22	<i>Croton macrostachyus</i>	2.58	3.29	2.33	0.44	2.92
23	<i>Dichrostachys cinerea</i>	0.67	0.43	0	0.44	0.85
24	<i>Dodonea angustifolia</i>	0.42	0.57	0.33	2.89	2.62
25	<i>Dovyalis abyssinica</i>	0.33	0.71	0.33	1.22	0.85
26	<i>Embelia schimperi</i>	0	0	0	1	0.23
27	<i>Entada abyssinica</i>	0	0.43	0.11	0	0.15
28	<i>Erythrina abyssinica</i>	1	0	0.11	0.78	1.92
29	<i>Euclea racemosa</i>	1	0.14	2	1.89	1.92
30	<i>Ficus palmata</i>	0	0	0	0	0.46
31	<i>Ficus sycomorus</i>	0	2	0	0	0
32	<i>Ficus thonningii</i>	0.5	0.71	0	0	0
33	<i>Ficus vasta</i>	0	0	0	0	1
34	<i>Flueggea virosa</i>	0.25	0.14	0.67	0	0.46
35	<i>Gardenia ternifolia</i>	0.92	0	0.78	1.33	1.62

36	<i>Grewia ferruginea</i>	2.5	1.43	0.67	1.89	1.62
37	<i>Hypericum quartinianum</i>	0	0.43	0	0	0.23
38	<i>Jasminum abyssinicum</i>	0.67	0.57	0.67	1.11	1.31
39	<i>Maesa lanceolata</i>	0.33	0.43	0.78	1.11	0.46
40	<i>Maytenus obscura</i>	0	0.43	0	0.44	0
41	<i>Maytenus undata</i>	2.58	1.71	3.67	2.89	1.85
42	<i>Millettia ferruginea</i>	0	1.71	0	0	0
43	<i>Mimusops kummel</i>	0.08	0	0	0.33	0
44	<i>Myrsine africana</i>	0.5	0	0	0.44	0.46
45	<i>Ocimum lamiifolium</i>	0.33	0	0.33	0	0
46	<i>Osyris quadripartita</i>	0.83	1.29	1.78	3.56	2.08
47	<i>Phoenix reclinata</i>	0	0	0	0.89	0.46
48	<i>Pittosporum abyssinicum</i>	0.08	0	0	0.67	0
49	<i>Pittosporum viridiflorum</i>	0.25	0	0.33	3.33	1.46
50	<i>premna schimperi</i>	1.58	1	0.44	3	2
51	<i>Pterolobium stellatum</i>	2.25	1.29	0.89	1.11	2.31
52	<i>Rhoicissus tridentate</i>	0.25	0.43	0	0.11	0.15
53	<i>Rhus glutinosa</i>	2.58	1.86	2.11	3.3	3.21
54	<i>Rosa abyssinica</i>	0.92	0.57	1.33	1	0.15
55	<i>Sapium ellipticum</i>	0.08	0	0	0	0.38
56	<i>senna singueana</i>	0.67	0.29	0.11	0.67	0.92
57	<i>Steganotaenia araliacea</i>	0.33	0.14	0.11	0.11	0.31
58	<i>Stereospermum kunthianum</i>	1.33	1.14	0	0	0.08
59	<i>Syzygium guineense</i>	0.25	0	4	2.11	0.31
60	<i>Terminalia brownii</i>	0.17	1.14	0.11	0.44	1
61	<i>Turraea holstii</i>	0	0	0.11	0	0
62	<i>Vernonia amygdalina</i>	0.25	0	0	0	0.23
63	<i>Vernonia myriantha</i>	0.25	1.71	0.44	0.33	0.38
64	<i>Ximenia americana</i>	0.25	0.14	0.78	1.11	0.77

Appendix 4: Importance Value Index

No.	Species	RF	RD	RD	IVI	priority class
1	<i>Carissa spinarum</i>	5.36	13.60	2.22	21.19	1
2	<i>Rhus glutinosa</i>	4.99	4.34	8.90	18.22	1
3	<i>Maytenus undata</i>	4.86	9.95	3.07	17.88	1
4	<i>Croton macrostachyus</i>	4.99	4.09	8.01	17.08	1
5	<i>Acacia lahai</i>	2.87	2.86	10.38	16.11	1
6	<i>Syzygium guineense</i>	2.00	1.23	7.69	10.91	2
7	<i>Osyris quadripartita</i>	4.11	3.63	2.90	10.64	2
8	<i>Calpurnia aurea</i>	3.99	4.83	1.38	10.19	2
9	<i>Dodonea angustifolia</i>	3.62	3.52	2.82	9.95	3
10	<i>Bersama abyssinica</i>	3.87	3.01	2.92	9.79	3
11	<i>Acanthus polystachius</i>	2.62	7.04	0.09	9.75	3
12	<i>Grewia ferruginea</i>	3.49	2.78	2.99	9.26	3
13	<i>premna schimperii</i>	3.74	2.63	2.12	8.49	3
14	<i>Pittosporum viridiflorum</i>	1.62	1.38	5.08	8.08	3
15	<i>Pterolobium stellatum</i>	2.99	3.98	0.82	7.79	3
16	<i>Acacia senegal</i>	2.49	1.71	3.51	7.71	3
17	<i>Euclea racemosa</i>	3.24	2.17	1.98	7.39	3
18	<i>Terminalia brownii</i>	1.50	0.83	4.76	7.08	3
19	<i>Ficus vasta</i>	0.25	0.12	6.46	6.83	3
20	<i>Acanthus sennii</i>	1.62	3.83	0.09	5.54	3
21	<i>Gardenia ternifolia</i>	2.49	1.25	1.78	5.52	3
22	<i>Erythrina abyssinica</i>	2.12	0.85	1.90	4.86	4
23	<i>Buddleja polystachya</i>	1.12	1.61	1.96	4.70	4
24	<i>Albizia gummifera</i>	1.00	0.69	2.81	4.50	4
25	<i>Vernonia myriantha</i>	1.25	1.77	1.26	4.28	4
26	<i>Dovyalis abyssinica</i>	1.50	0.92	1.51	3.93	4
27	<i>Maesa lanceolata</i>	1.12	1.21	1.48	3.82	4
28	<i>Capparis tomentosa</i>	1.50	1.81	0.50	3.81	4
29	<i>Combretum collinum</i>	1.62	0.45	1.68	3.75	4
30	<i>senna singueana</i>	1.87	0.80	0.83	3.50	4
31	<i>Albizia schimperiana</i>	1.50	0.35	1.58	3.43	4
32	<i>Jasminum abyssinicum</i>	2.00	0.72	0.41	3.13	4
33	<i>Rosa abyssinica</i>	1.62	1.06	0.42	3.10	4
34	<i>Ximenia americana</i>	1.37	0.91	0.76	3.04	4
35	<i>Dichrostachys cinerea</i>	1.37	0.52	0.64	2.53	4

36	<i>Stereospermum kunthianum</i>	0.87	0.23	1.23	2.34	4
37	<i>Myrsine africana</i>	0.75	1.26	0.26	2.27	4
38	<i>Ficus sycomorus</i>	0.25	0.05	1.94	2.24	4
39	<i>Steganotaenia araliacea</i>	0.87	0.34	0.60	1.81	4
40	<i>Phoenix reclinata</i>	0.87	0.20	0.69	1.76	4
41	<i>Millettia ferruginea</i>	0.37	0.60	0.69	1.67	4
42	<i>Flueggea virosa</i>	0.75	0.51	0.19	1.45	4
43	<i>Rhoicissus tridentate</i>	0.87	0.22	0.28	1.37	4
44	<i>Clausena anisata</i>	0.75	0.43	0.15	1.33	4
45	<i>Albizia malacophylla</i>	0.62	0.35	0.33	1.30	4
46	<i>Acacia persiciflora</i>	0.37	0.14	0.76	1.28	4
47	<i>Pittosporum abyssinicum</i>	0.37	0.49	0.40	1.27	4
48	<i>Ficus thonningii</i>	0.25	0.11	0.89	1.25	4
49	<i>Acokanthera schimperi</i>	0.50	0.34	0.15	0.98	5
50	<i>Entada abyssinica</i>	0.50	0.32	0.16	0.98	5
51	<i>Sapium ellipticum</i>	0.25	0.12	0.51	0.89	5
52	<i>Embelia schimperi</i>	0.37	0.34	0.14	0.85	5
53	<i>Maytenus obscura</i>	0.25	0.35	0.20	0.81	5
54	<i>Hypericum quartinianum</i>	0.25	0.09	0.41	0.75	5
55	<i>Ocimum lamiifolium</i>	0.37	0.32	0.03	0.73	5
56	<i>Bridelia micrantha</i>	0.25	0.15	0.22	0.63	5
57	<i>Vernonia amygdalina</i>	0.25	0.05	0.21	0.50	5
58	<i>Brucea antidysenterica</i>	0.37	0.08	0.05	0.50	5
59	<i>Celtis africana</i>	0.25	0.15	0.09	0.50	5
60	<i>Ficus palmata</i>	0.12	0.14	0.22	0.48	5
61	<i>Mimusops kummel</i>	0.25	0.06	0.04	0.35	5
62	<i>Cordia africana</i>	0.12	0.03	0.11	0.26	5
63	<i>Allophylus abyssinicus</i>	0.12	0.06	0.03	0.21	5
64	<i>Turraea holstii</i>	0.12	0.02	0.02	0.16	5
	total	100.00	100.00	100.00	300.00	

Appendix 5: Density per hectare of seedlings, saplings, mature trees and shrubs of woody species

No.	Species	Mature trees/shrubs/ha	Seedlings/ha	Saplings/ha
1	<i>Acacia lahai</i>	93	0	11.2
2	<i>Acacia persiciflora</i>	4.5	0	0
3	<i>Acacia senegal</i>	55.5	38.4	54.4
4	<i>Acanthus polystachius</i>	229	353.6	592
5	<i>Acanthus sennii</i>	124.5	89.6	179.2
6	<i>Acokanthera schimperi</i>	11	46.4	35.2
7	<i>Albizia gummifera</i>	22.5	60.8	100.8
8	<i>Albizia malacophylla</i>	11.5	0	12.8
9	<i>Albizia schimperiana</i>	11.5	0	3.2
10	<i>Allophylus abyssinicus</i>	2	4.8	0
11	<i>Bersama abyssinica</i>	98	43.2	88
12	<i>Bridelia micrantha</i>	5	0	0
13	<i>Brucea antidysenterica</i>	2.5	46.4	36.8
14	<i>Buddleja polystachya</i>	52.5	0	0
15	<i>Calpurnia aurea</i>	157	273.6	228.8
16	<i>Capparis tomentosa</i>	59	340.8	96
17	<i>Carissa spinarum</i>	442.5	57.6	171.2
18	<i>Celtis africana</i>	5	0	0
19	<i>Clausena anisata</i>	14	265.6	156.8
20	<i>Combretum collinum</i>	14.5	81.6	65.6
21	<i>Cordia africana</i>	1	0	0
22	<i>Croton macrostachyus</i>	133	4.8	0
23	<i>Dichrostachys cinerea</i>	17	0	0
24	<i>Dodonea angustifolia</i>	114.5	147.2	224
25	<i>Dovyalis abyssinica</i>	30	38.4	38.4
26	<i>Embelia schimperi</i>	11	0	0
27	<i>Entada abyssinica</i>	10.5	0	0
28	<i>Erythrina abyssinica</i>	27.5	0	6.4
29	<i>Euclea racemosa</i>	70.5	193.6	142.4
30	<i>Ficus palmata</i>	4.5	0	0

30	<i>Ficus palmata</i>	4.5	0	0
31	<i>Ficus sycomorus</i>	1.5	0	0
32	<i>Ficus thonningii</i>	3.5	0	1.6
33	<i>Ficus vasta</i>	4	33.6	43.2
34	<i>Flueggea virosa</i>	16.5	0	0
35	<i>Gardenia ternifolia</i>	40.5	73.6	94.4
36	<i>Grewia ferruginea</i>	90.5	142.4	230.4
37	<i>Hypericum quartinianum</i>	3	0	0
38	<i>Jasminum abyssinicum</i>	23.5	296	129.6
39	<i>Maesa lanceolata</i>	39.5	54.4	52.8
40	<i>Maytenus obscura</i>	11.5	33.6	35.2
41	<i>Maytenus undata</i>	323.5	196.8	710.4
42	<i>Millettia ferruginea</i>	19.5	72	73.6
43	<i>Mimusops kummel</i>	2	3.2	0
44	<i>Myrsine africana</i>	41	182.4	158.4
45	<i>Ocimum lamiifolium</i>	10.5	33.6	33.6
46	<i>Osyris quadripartita</i>	118	35.2	75.2
47	<i>Phoenix reclinata</i>	6.5	43.2	36.8
48	<i>Pittosporum abyssinicum</i>	16	0	20.8
49	<i>Pittosporum viridiflorum</i>	45	52.8	57.6
50	<i>prema schimperii</i>	85.5	33.6	73.6
51	<i>Pterolobium stellatum</i>	129.5	1424	140.8
52	<i>Rhoicissus tridentate</i>	7	35.2	33.6
53	<i>Rhus glutinosa</i>	141	81.6	105.6
54	<i>Rhamnus prinoides</i>	0	14.4	0
55	<i>Rosa abyssinica</i>	34.5	36.8	48
56	<i>Sapium ellipticum</i>	4	0	0
57	<i>senna singueana</i>	26	40	80
58	<i>Steganotaenia araliacea</i>	11	0	0
59	<i>Stereospermum</i>	7.5	56	57.6
60	<i>Syzygium guineense</i>	40	212.8	75.2
61	<i>Terminalia brownii</i>	27	36.8	33.6
62	<i>Turraea holstii</i>	0.5	1.6	0
63	<i>Vernonia amygdalina</i>	1.5	0	0
64	<i>Vernonia myriantha</i>	57.5	86.4	115.2
65	<i>Ximenia americana</i>	29.5	0	22.4
Total		3252.5	5398.4	4782.4

Appendix 6: Environmental variables based on their p-value and AKaike Information Criterion (AIC), Key: K= Potassium, OM= Organic Matter, OC= Organic Carbon, Ca= Calcium, CEC= Cation Exchange Capacity, Mg= Magnesium, EC= Electron conductivity, Na= Sodium, P= Phosphorus, TN= Total Nitrogen, PH= Power of Hydrogen

Variables	Df	AI C=276.48	F	Pr (>F))
K	1	276.53	1.628	0.010**
OM	1	276.56	1.6063	0.15*
OC	1	276.56	1.6059	0.010**
Ca	1	276.60	1.5690	0.005**
Silt	1	276.67	1.5099	0.020*
Sand	1	276.67	1.5099	0.035*
CEC	1	276.69	1.4897	0.030*
Aspect	1	276.81	1.3852	0.030*
Altitude	1	276.82	1.3822	0.050*
Cutting	1	276.98	1.2484	0.135
Grazing	1	276.05	1.1832	0.175
Browsing	1	277.17	1.0820	0.315
Slope	1	277.24	1.0232	0.410
Mg	1	277.41	2.5388	0.005**
EC	1	277.66	2.7650	0.005**
Na	1	278.51	3.5297	0.005**
Clay	1	279.48	4.4197	0.005**
P	1	279.485	4.7680	0.005 **
TN	1	280.28	5.1691	0.005 **
pH	1	280.57	5.4460	0.005**
Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1				